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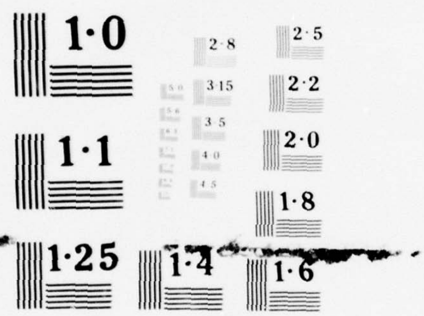

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LIQUID WATER CONTENT ANALYZER

Instruction Manual

Raytheon Company
Boston Post Road
Wayland, Massachusetts 01778

September 1975

Final Report

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This manual provides a description of the liquid water content analyzer software and operator interaction with the analyzer system.

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SECTION 1. INTRODUCTION

The Liquid Water Content Analysis System consists of three major hardware elements and a computer program. The three hardware elements are the Scan Converter, the Digital Integrator and the Interdata 7/32 computer. The Scan Converter and Digital Integrator were developed and delivered on previous contracts. Operation of the Digital Integrator is explained in the Equipment Information Report for the Precision Digital Video Integrator, Model D-A11-RS dated July 1974, while the Scan Converter is described and explained in the Scan Converter for Liquid Water Content Analyzer Final Report dated July 1975. The purpose of this manual is to provide information essential to the operation of the system through interaction with the computer and the computer program.

SECTION 2. PROCESSING MODE

As shown in Figure 2-1, the computer program has three basic operating modes: RECORD, PLAYBACK and LIQUID WATER CONTENT ANALYSIS. The record and playback modes referred to in this respect are record only and playback only. The liquid water content analysis mode is the primary operating mode and as such will be considered in some detail.

In the paragraphs that follow references will be made to the various constants, variables, tables and flags used by the computer program. In some cases it may be necessary to refer to the tables in Section 3 to understand these references. All teletype messages, allowed responses and subsequent action taken by the program are presented in Section 4. A brief description of all subroutines is provided in Section 5, while more detailed descriptions of all major subroutines are included in the Appendices.

2.1 RECORD Mode

The record only mode is used to record the raw integrator digital output together with the radar ancillary data and time from the scan converter. Data is recorded in the form of table VBUF. The radar calibration constant associated with the data to be recorded is requested on the teletype before the recording is started. The teletype is armed during the recording process in order that the recording can be stopped by typing HALT. A tape recorder malfunction or end-of-tape will also terminate the recording.

2.2 PLAYBACK Mode

The playback only mode is used to playback data recorded in either the record only mode or the liquid water content analysis mode for display on the scan converter. The time of the recording and the integration parameters used during the recording are output to the teletype from data

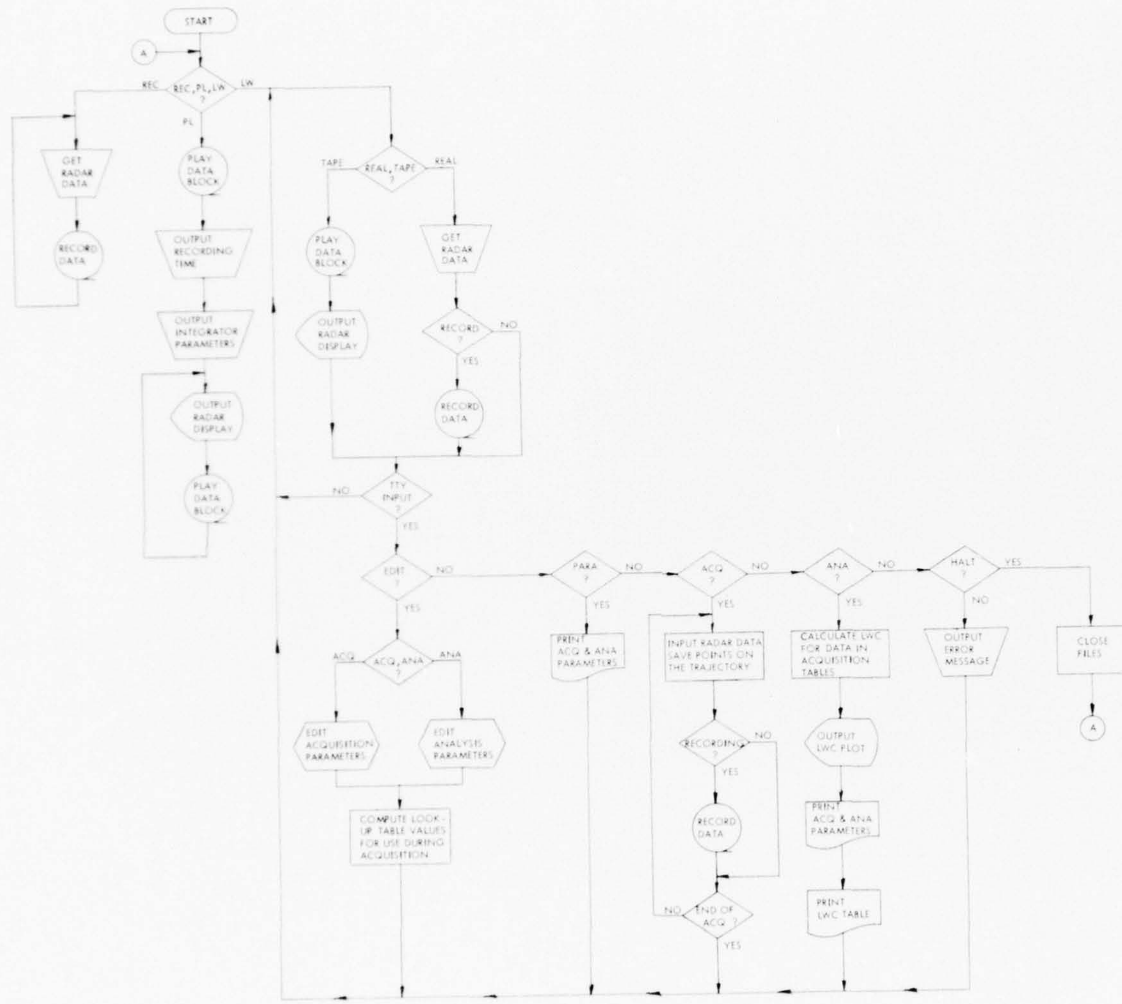

Figure 2-1. System Flow Diagram

in the first recorded block. The teletype is armed during the playback process in order to permit termination of the process by typing HALT. A tape recorder malfunction or end-of-file will also terminate the playback process.

2.3 LIQUID WATER CONTENT ANALYSIS Mode

Liquid water content analysis can be performed on either real-time data or previously recorded data. If real-time data is to be used, the operator can choose to record the data also. After the input mode is established, the program goes into a holding loop to wait for teletype input direction. While waiting data is recorded, played-back or ignored at a speed determined by the integrator. Each of the permissible teletype commands and the action that follows them are summarized in the following paragraphs.

2.3.1 EDIT

Typing EDIT will permit the operator to change any of the acquisition or analysis parameters. These parameters are divided into two groups; the operator must select which parameter set he wishes to edit: ACQ or ANA.

2.3.1.1 ACQuisition

If the operator selects ACQ, the acquisition parameters are requested along with their format in the following order: DIS, PHIT, RCM, HM, HO, HE. From these values and the integration parameters the following values are computed: CPHIT, SPHIT, COPHIT, HMR, DR, RCR.

The program then builds a table, RLUT, which is unique to this geometry. Addressed by elevation angle PHI, this table includes the range cell number R(PHI) closest to the trajectory for every possible PHI. Since we have 12-bit angle coding but elevation is restricted to one quadrant, the table must have 1024 entries. Only a small fraction of the entries in RLUT will actually be used, but we need them all because the actual values of PHI at each integrator output (dump) are not known apriori since the antenna scan is not synchronous with the integrator timing.

The calculations to fill RLUT, described by

$$R(PHI)=DIS/(COS\ (PHI) - SIN\ (PHI)\ COT\ (PHIT)) \quad (1)$$

involve use of the circular CORDIC subroutine described in the Appendix for determination of the transcendental functions. The COT (PHIT) term needs to be calculated only once, while the SIN(PHI) and COS (PHI) terms must be obtained for each PHI in the Table. The CORDIC routine outputs both SIN(PHI) and COS(PHI) simultaneously.

The values of R(PHI) in RLUT are scaled in terms of a range cell number between DIS and 1023, so that 10-bit words are required. If memory usage is a problem, schemes for reducing this word length to 8-bits can be envisioned since R(PHI) must be monotonic. For the present, 16-bit half words will be used. The extra bits could be used as flags to show where the range goes beyond 1024 or within the clutter range RC.

During this initialization phase, the altitude for each PHI could have been easily calculated. However; the resulting increased data handling requirements in the acquisition phase to follow would have lengthened the critical execution time of that phase.

Program control returns to the holding loop to await further teletype input instructions.

2.3.1.2 ANAlysis

If the operator selects ANA, the analysis parameters are requested along with their format in the following order: DH, HI1, HI2, Z2INP, HI3, Z3INP, T1, T2, T3, S1, S2, S3, S4, Q1, Q2, Q3, Q4, DISNUM. Acquisition parameters are then recalculated and control returned to the holding loop.

2.3.2 PARAmeter Display

If the operator selects PARA, the program will print all acquisition and analysis parameters on the line printer. In this manner the operator can review the parameters and determined which, if any, of them need to be changed by EDITing.

After the parameters have been printed, program control is returned to the holding loop to await further teletype input instructions.

2.3.3 ACQuisition Phase

If the operator is satisfied with the parameters that have been established in the initialization phase, he instructs the processor (through the TTY) to enter the acquisition phase whereupon his interaction with the machine ceases until this phase has been completed.

As shown in the flow diagram of Figure 2-2, the acquisition phase begins when the elevation scan reaches one or the other of its turnaround limits. A table called VBUF is periodically being refreshed with new video data for each of 1024 range cells, and certain corresponding ancillary data of which only PHI is of concern here. VBUF is filled via DMA transfers from either the integrator (real-time) or mag tape. The contents of VBUF at a given time corresponds to one of the sectors shown in Figure 2-3. The algorithm within the loop uses data from RLUT to define variable length block transfers from VBUF to another table, VTAB. For ranges below RCR V(RCR) is entered into VTAB instead of V(R). When the antenna reaches the second turnaround, the operator is instructed that the acquisition phase has been completed. VTAB now contains data corresponding to the shaded area of Figure 2-2; these data are inputs for the analysis phase to follow.

Because the integrator could be set up for as few as 64 sweeps integrated at a PRF of 960 $sec.^{-1}$, the time available for one pass through the loop in Figure 2-2 is 66.66 milliseconds. For this reason, every effort has been made to minimize processing within the loop; even at the expense of increased complexity and time in the two other phases.

The radar data associated with the maximum elevation angle greater than PHIMAX reached during the acquisition phase is saved in a table (RBHM) to be used as data for those points along the trajectory above HM or beyond the maximum radar range.

When acquisition has been completed, control is either returned to the holding loop to await teletype input instruction or, if not in the real-time recording mode, control is passed directing to the ANALYSIS phase software.

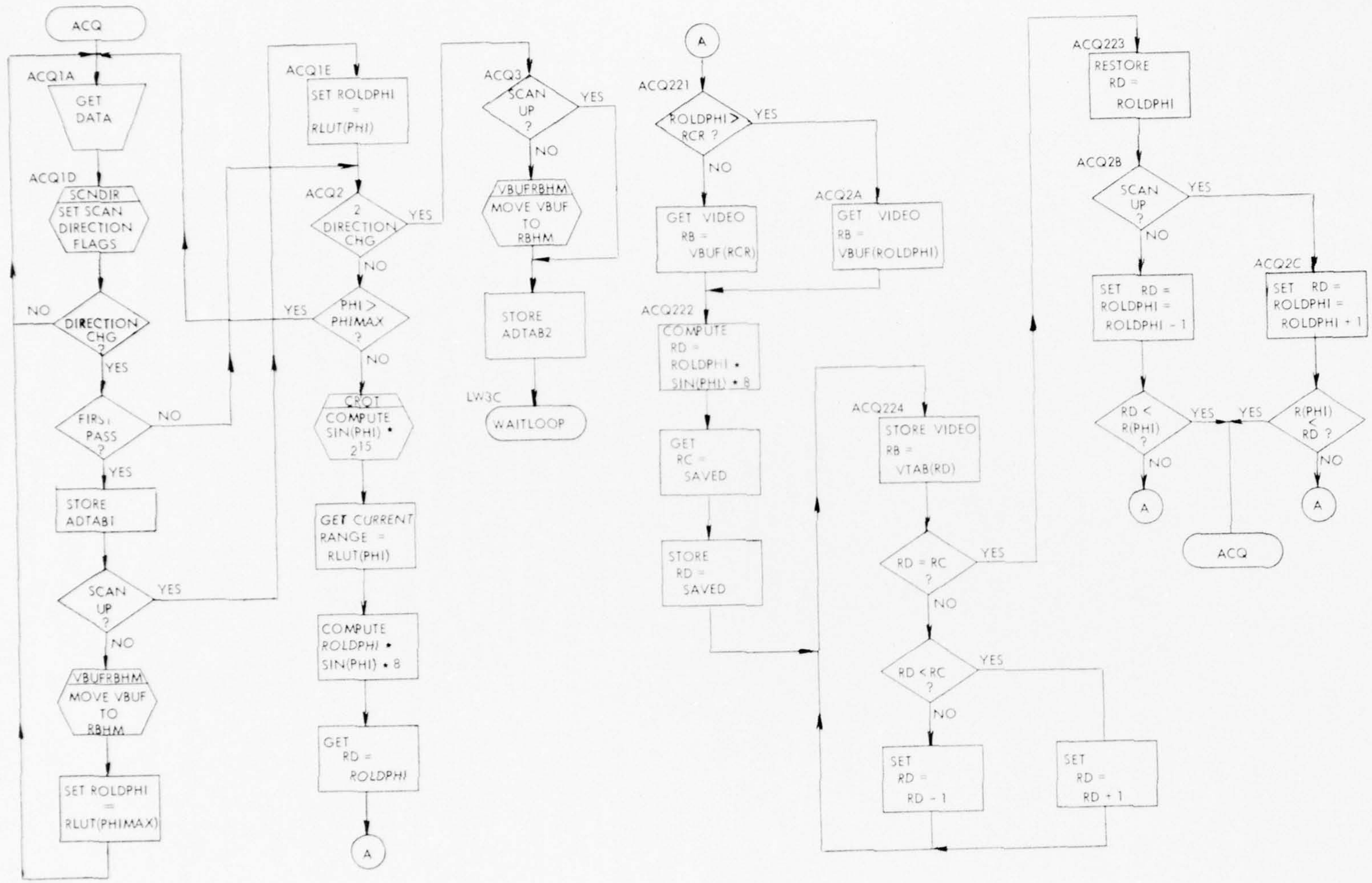

Figure 2-2. Data Acquisition

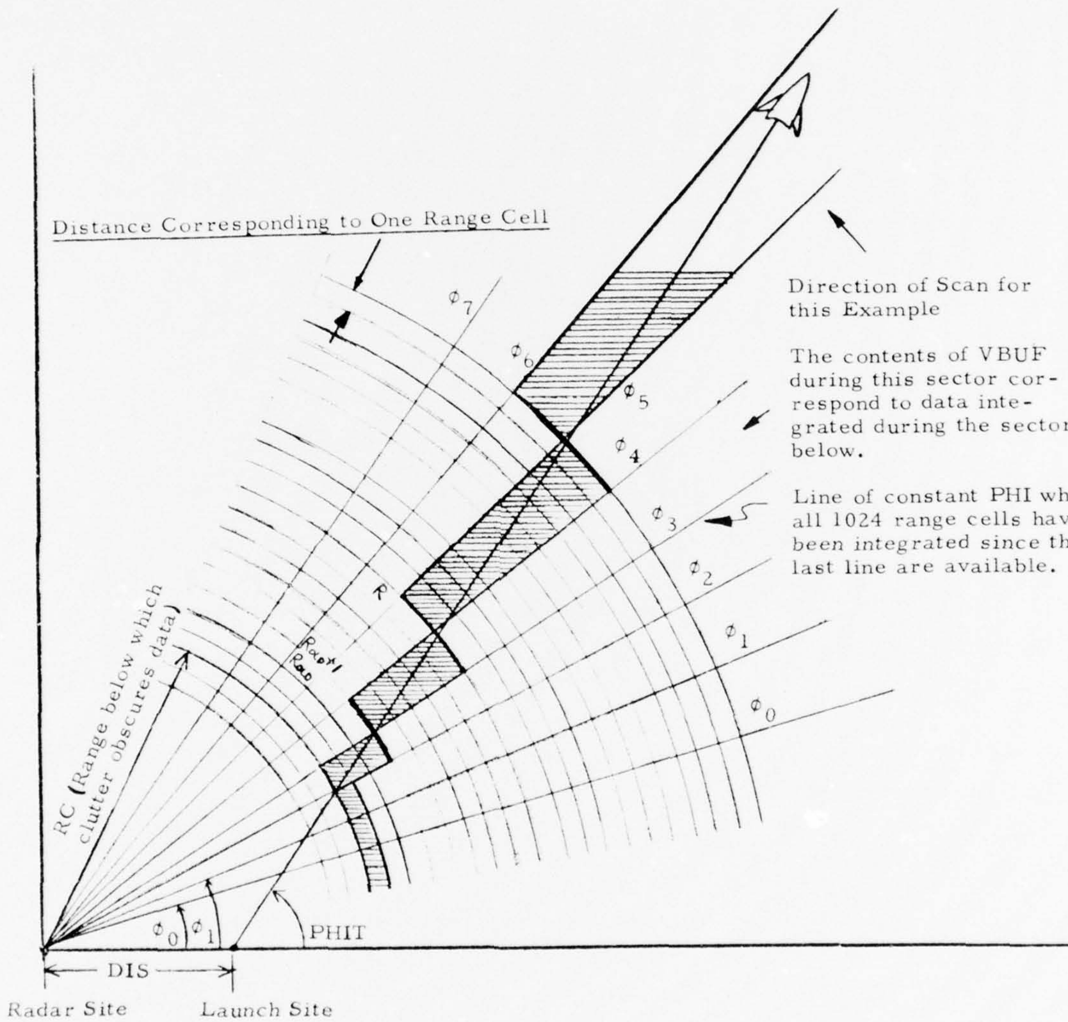

Figure 2-3. LWCA Data Acquisition Geometry. Integrated Log Video for the Shaded Area is Entered Into VTAB.

2.3.4 ANAlysis

2.3.4.1 Computation

The analysis phase software computes the liquid water content density as a function of altitude based on the values of radar video stored in the tables VTAB and RBHM and the analysis parameters.

The program first computes the altitude extremes for which there are data and then averages the video over the altitude resolution steps (DH) between these extremes. Transition altitudes are then computed in units of altitude steps and, for H2 and H3, as a function of Z2INP and Z3INP, respectively. The coefficients (Q) and exponents (S) for each altitude region are next interpolated across each of the transition regions T1, T2, and T3.

Values of the logarithm of the liquid water content density and liquid water content density are computed in the subroutine LWC for each altitude step and saved in tables LWTAB and WTAB, respectively.

The calculations used to determine the entries for tables LWTAB and WTAB are presented in the appendices titled "Analytic Determination of Liquid Water Content", "Range of Liquid Water Content", and "LWC Subroutine".

2.3.4.2 Output

When the liquid water content calculations have been completed, control is transferred to a series of program routines for outputting the analysis data. The first of these routines, LWCPLT, outputs the data from LWTAB to the scan converter display designated by DISNUM. (A programming description for display interface programs is included in the appendix titled "Display Data Port Programming".) After the plot of liquid water content versus altitude has been presented on the scan converter display, the program outputs all acquisition and analysis parameters to the line printer and then prints a table of averaged radar video and calculated liquid water content density (WTAB) on the line printer.

Program control is then transferred back to the holding loop to await further teletype input instructions.

SECTION 3. CONSTANTS, VARIABLES, FLAGS AND TABLES

3.1 Constants and Variables

Table 3-1 lists all the significant program constants and variables. For each named constant/variable there is a brief description, a range of values, the unit of the number, the source and the scaling of the constant or variable.

3.2 Flags

Table 3-2 on page 3-11 lists the significant program flags together with their use, size, number of states and state definitions.

3.3 Tables

Program data tables are described in Figures 3-1 through 3-8. Applicable notes are included with each figure.

Table 3-1. Constants and Variables

Name	Description	Range Without Scaling	Units	Source: Format	Multiplier Before Storage	Value of LSB
A	EQU 10	-	-	-	-	-
ADC	EQU 4	-	-	-	-	-
ALTA	Half-word variable altitude. Computed by subroutine ALTCOMP	$0 \le ALTA \le 15000$	Meters	Computed	-	1 meter
ANAD1 ANAD2 ANAD3	Full-word variables; Number of altitude steps across transition region 1, 2 and 3, respectively	$0 \le ANAD \le 9999$	-	Computed	-	1
ASCIIA	20-byte storage area	-	-	-	-	-
B	EQU 11	-	-	-	-	-
COEFF	EQU 5	-	-	-	-	-
COPHIT	Full-word variable; cotangent of the launch trajectory angle (PHIT)	$\cot 90^\circ < COPHIT \le \cot 20^\circ$	-	Computed	2^{14}	2^{-14}
CPHIT	Full-word variable; cosine of the launch trajectory angle (PHIT)	$\cos 90^\circ < CPHIT \le \cos 20^\circ$	-	Computed	2^{15}	2^{-15}
CVTASC	Full-word storage area	-	-	-	-	-
DAY	1.5 byte variable; Day of year in BCD	$001 \le DAY \le 999$	Days	Ancillary: N (4) N (4) N (4)	-	1 day
DAYASC	Full-word variable; Day of year in ASCII	$001 \le DAY \le 999$	Days	Converted from DAY	-	1 day
DH	Full-word variable; Altitude quantization step size	$1 \le DH \le 999$	Meters	TTY:NNN	-	1 meter
DIS	Full word variable. Distance from radar to launch site	$2500 \le DIS \le 200000$	Meters	TTY:NNNNNN	-	1 meter

Table 3-1. (Continued)

Name	Description	Range Without Scaling	Units	Source: Format	Multiplier Before Storage	Value of LSB
DISNUM	Full word variable. Number of display used for LWC plot	$1 \leq$ DISNUM ≤ 4	-	TTY:N	-	1
DR	Half word variable. Distance from radar to launch site in range cell units	$8 \leq$ DR ≤ 1024	Range cells	Computed	-	1 range cell
DRSL15	Full word variable DR scaled up by factor of 2^{15}	$2^{18} \leq DR \leq 2^{25}$	Range cells	Computed	-	2^{-15} range cell
EXPONENT	EQU 4	-	-	-	-	-
EXTRA	Half-word storage area	-	-	-	-	-
GR	Half-word variable Ground range in range cell units from radar to maximum trajectory extent GR = DR + HMR *COPHIT	$8 \leq$ GR ≤ 1024	Range cells	Computed	-	1 range cell
H1 H2 H3	Full-word variables. Transition altitudes in units of altitude steps	$0 < H < 180$ $H1 \leq H2 \leq H3$	Altitude steps	Computed	-	1 altitude step
HE	Full word variable Maximum altitude for computing LWC	$1 \leq$ HE ≤ 15000	Meters	TTY:NNNNN	-	1 meter
HI1 HI2 HI3	Full word variables Initial values for transition altitudes	$1 \leq$ HI ≤ 15000	Meters	TTY:NNNNN	-	1 meter
HM	Half-word variable Maximum altitude of interest along the trajectory (TOPS)	$1 \leq$ HM ≤ 15000	Meters	TTY:NNNNN	-	1 meter
HMR	Half-word variable HM in range cell units	$0 \leq$ HMR ≤ 200	Range cells	Computed	-	1 range cell

Table 3-1. (Continued)

Name	Description	Range Without Scaling	Units	Source: Format	Multiplier Before Storage	Value of LSB
HO	Full-word variable Minimum altitude for computing LWC	$0 \leq HO \leq 15000$	Meters	TTY:NNNNN	-	1 meter
HUNDRED	Half-word constant Decimal 100	-	-	-	-	-
I	EQU 10	-	-	-	-	-
LOGW	EQU 6	-	-	-	-	-
LWCBLK	Full-word constant Four ASCII blanks	-	-	-	-	-
NINT	Byte variable. Coded number of sweeps integrated	Eleven values: 1, 2, 4, ... 512, 1024.	-	Integrator: 1010 = 1, 1001 = 2, 1000 = 4, 0111 = 8, 0110 = 16, 0101 = 32, 0100 = 64, 0011 = 128, 0010 = 256, 0001 = 512, 0000 = 1024.	-	coded
NINTBIN	Full word variable Number of sweeps Integrated	$1 \leq NINTBIN \leq 1024$	-	Converted from NINT	-	1
OLDPHI	Half-word variable Antenna elevation angle associated with previous integrator dump	$0 \leq OLDPHI < 90$	Degrees	Ancillary data port: *12 bit binary, MSB = 180°*	-	$\frac{90}{1024}$ degrees
ONEK1	Full word constant Decimal 19898 Used in conjunction with the CORDIC subroutines	-	-	-	-	-
ONEOVKLG	Half word constant Decimal 19898 Used with CORDIC subroutines	-	-	-	-	-
PHI	Half-word variable Radar antenna elevation angle	$0 \leq PHI < 90$	Degrees	Ancillary data port 12 bit binary, MSB = 180°	-	$\frac{90}{1024}$ degrees

Table 3-1. (Continued)

Name	Description	Range Without Scaling	Units	Source: Format	Multiplier Before Storage	Value of LSB
PHIMAX	Half-word variable Antenna elevation angle at which the antenna beam intersects the trajectory at an altitude equal to or greater than HM (TOPS)	$0 \leq PHIMAX < 90$	Degrees	Computed while building RLUT	-	$\frac{90}{1024}$ degrees
PHIMAX1	Half-word variable Maximum antenna elevation angle occurring during data acquisition	$0 \leq PHIMAX1 < 90$	Degrees	Computed from ADTAB1 and ADTAB2	-	$\frac{90}{1024}$ degrees
PHIMIN	Half-word variable Minimum antenna elevation angle occurring during data acquisition	$0 \leq PHIMIN < 90$	Degrees	Computed from ADTAB1 and ADTAB2	-	$\frac{90}{1024}$ degrees
PHIT	Half-word variable Launch trajectory	$20 \leq PHIT < 90$	Degrees	TTY:NN.NN	$\frac{1024}{90}$	$\frac{90}{1024}$ degrees
PTDAY	Full-word constant ASCII "DAY"	-	-	-	-	-
Q1 Q2 Q3 Q4	Full-word variables Phase related constants used to calculate liquid water content density (Coefficient)	$100 \leq Q \leq 200000$	-	TTY:NNNNNN	-	1
Q12 Q23 Q34	Full-word variables Interpolation increment for Q values. Equal to difference across transition region divided by number of altitude steps across the transition region	$100 \leq Q \leq 200000$	-	Computed	-	1
R0	EQU 0	-	-	-	-	-
R10	EQU 10	-	-	-	-	-
R11	EQU 11	-	-	-	-	-
R12	EQU 12	-	-	-	-	-

Table 3-1. (Continued)

Name	Description	Range Without Scaling	Units	Source: Format	Multiplier Before Storage	Value of LSB
R13	EQU 13	-	-	-	-	-
R14	EQU 14	-	-	-	-	-
R15	EQU 15	-	-	-	-	-
R2	EQU 2	-	-	-	-	-
R3	EQU 3	-	-	-	-	-
R4	EQU 4	-	-	-	-	-
R5	EQU 5	-	-	-	-	-
R6	EQU 6	-	-	-	-	-
R7	EQU 7	-	-	-	-	-
R8	EQU 8	-	-	-	-	-
R9	EQU 9	-	-	-	-	-
RA	EQU 10	-	-	-	-	-
RAWPHIT	Full-word variable Launch trajectory	$0 \leq$ RAWPHIT < 90	Degrees	TTY:NN.NN	100	10^{-2} degrees
RAWRCC	Full-word variable Radar calibration constant	$0 \leq$ RCC ≤ 99	dB	TTY:NN	-	1 dB
RB	EQU 11	-	-	-	-	-
RC	EQU 12	-	-	-	-	-
RCC	Byte variable Radar calibration constant	$0 \leq$ RCC ≤ 99	dB	TTY:NN	$\frac{256}{100}$	$\frac{100}{256}$ dB
RCCBIN	Full-word variable Radar calibration constant	$0 \leq$ RCC ≤ 99	dB	TTY:NN	$\frac{256}{100}$	$\frac{100}{256}$ dB
RCEL	Byte variable Coded range cell size	Three values 0.5, 1.0, 2.0	Microsec.	Integrator: 001 = 0.5, 010 = 1.0, 100 = 2.0	-	coded

Table 3-1. (Continued)

Name	Description	Range Without Scaling	Units	Source: Format	Multiplier Before Storage	Value of LSB
RCELM	Half-word variable Range cell size in meters	75, 150, 300	Meters	Converted from RCEL	-	1 meter
RCI	Byte variable Coded range integration	Five values: 1, 2, 4, 8, 16.	Range cells	Integrator 000 = 1, 010 = 2, 011 = 4, 100 = 8, 101 = 16.	-	coded
RCIBIN	Full-word variable Range integration	1, 2, 4, 8, 16	Range cells	Converted from RCI	-	1 range cell
RCM	Half-word variable Range extent of ground clutter	0<RCM≤ 25000	Meters	TTY:NNNNN	-	1 meter
RCR	Half-word variable Range extent of ground clutter in range cell units	0≤ RCR< 334	Range cells	Computed	-	1 range cell
RD	EQU 13	-	-	-	-	-
RE	EQU 14	-	-	-	-	-
REGSTOR	16 full-words storage area	-	-	-	-	-
RF	EQU 15	-	-	-	-	-
RM	Half-word variable Radar range to maximum altitude along the trajectory (TOPS)	8 < RM≤ 1024	Range cells	Computed	-	1 range cell
RNUM	Byte variable Coded number of range cells processed by integrator	Four values: 256, 512, 768, 1024.	Range cells	Integrator 11 = 256, 10 = 512, 01 = 768, 00 = 1024.	-	coded
RNUMBIN	Full-word variable Number of range cells processed by the integrator	256, 512, 768 1024	Range cells	Converted from RNUM	-	1 range cell

Table 3-1. (Continued)

Name	Description	Range Without Scaling	Units	Source: Format	Multiplier Before Storage	Value of LSB
ROLDPHI	Half-word variable The range in range cells from the radar to the intersection with the launch trajectory for the antenna elevation angle associated with the previous integrator dump	$8 < ROLDPHI \leq 1024$	Range cells	Computed from RLUT	-	1 range cell
S1 S2 S3 S4	Full-word variables Phase related constant for calculating liquid water content density (exponent)	$1.63 < S < 2.54$	-	TTY:N.NN	100	10^{-2}
S12 S23 S34	Full-word variables Interpolation increment for S values. Equal to difference in S values on each side of transition region divided by number of altitude steps across the transition region	$1.63 < S < 2.54$	-	Computed	100	10^{-2}
SPHIT	Half-word variable Sine of launch trajectory angle (PHIT)	$\sin 20^\circ \leq SPHIT < \sin 90^\circ$	-	Computed	2^{15}	2^{-15}
STOR	16 full-word storage area	-	-	-	-	-
T1 T2 T3	Full word variables Thickness of the transition regions	$0 < T \leq 9999$	Meters	TTY:NNNN	-	1 meter
TEN	Half-word constant Decimal 10	-	-	-	-	-
TEN23	Half-word constant Decimal 1023	-	-	-	-	-

Table 3-1. (Continued)

Name	Description	Range Without Scaling	Units	Source: Format	Multiplier Before Storage	Value of LSB
THETA	Half-word variable Radar antenna azimuth angle	$0 \leq THETA < 360$	Degrees	Ancillary data port 12 bit binary, MSB = 180	-	$\frac{90}{1024}$ degrees
TIME	Half-word plus half byte variable Time of day	$0000 \leq TIME < 2400$	Hours, Minutes, Seconds	Ancillary: H H M M S S (2)(4) (3) (4) (3)(4)	-	-
TIMEASC	Two full-word variable Time of day in ASCII	$0000 \leq TIME < 2400$	Hours, Minutes Seconds	Converted from TIME	-	-
TIMEBCD	Full-word variable Time of day in BCD	$0000 \leq TIME < 2400$	Hours, Minutes Seconds	Converted from TIME	-	-
TPDEVNO	EQU X'85' Tape recorder device number	-	-	-	-	-
TTYDEVNO	EQU 2 TTY device number	-	-	-	-	-
TTYINPUT	Three full-word storage area	-	-	-	-	-
TTYSAVE	Full-word storage area	-	-	-	-	-
VIDEO	EQU 3	-	-	-	-	-
VRCC	Half-word variable Radar calibration constant	$0 \leq VRCC \leq 99$	dB	TTY:NN	$\frac{256}{100}$	$\frac{100}{256}$ dB
VTABMAX	Half-word variable Address of last entry into VTAB	-	-	Computed	-	-
WDENSITY	EQU F	-	-	-	-	-
WLINK	EQU 8	-	-	-	-	-

Table 3-1. (Continued)

Name	Description	Range Without Scaling	Units	Source: Format	Multiplier Before Storage	Value of LSB
X	EQU 11	-	-	-	-	-
Y	EQU 12	-	-	-	-	-
Z	EQU 13	-	-	-	-	-
Z2 Z3	Full-word variables Reflectivities used to determine H2 and H3	$0 \leq Z \leq 99$	dB	Converted from Z2 INP and Z3INP	$\frac{256}{100}$	$\frac{100}{256}$ dB
Z2INP Z3INP	Full-word variables Inputs for Z2 and Z3	$0 \leq Z \leq 99$	dB	TTY:NN	-	1 dB
ZERO	EQU 0	-	-	-	-	-

Table 3-2. Flags

Name	Use	Size	No. of States	State Definition
DAQFLG	Scan direction flag. Used to avoid start up errors. Indicates number of times SCNDIR (acquisition scan direction subroutine has been called)	1 byte	3	0 = no calls to scan direction subroutine SCNDIR 1 = one call to SCNDIR 2 = 2 or more calls to SCNDIR
DAQFLG1	Left byte: used to indicate that ancillary data for first turn-around has been stored	2 bytes	Left byte: 2	0 = data not stored 1 = data stored
	Right byte: used to count number of scan direction turnarounds		Right byte: 3	0 = no direction changes 1 = one direction change 2 = two direction changes
DAQFLG2	Used to indicate scan direction	1 byte	2	0 = scanning down (PHI decreasing) 1 = scanning up (PHI increasing)
INMODE	Defines processing mode for the program	2 bytes	5	0 = Liquid Water Content Analysis (LWCA), magnetic tape input. 1 = LWCA, real time input, no recording 2 = LWCA, real time input, recording 3 = Record only 4 = Playback only
PLBCKFLG	Used to know if the data played back is the first data record. If it is the first record, various parameters including date of recording are printed on the teletype	2 bytes	2	0 = 1st tape data record 1 = subsequent tape data record
PHIDIR	Scan direction flag in the radar drivers	2 bytes	2	-1 = scanning down +1 = scanning up
TPAVAFLG	Used to indicate that tape unavailable TTY message has been output	2 bytes	2	0 = message has not been output 1 = message has been output
TPSTAT	Tape recorder status and command flag	1 byte	2 (There are only two command states; there are several status conditions)	Bit 7 = 0 = tape write = 1 = tape read

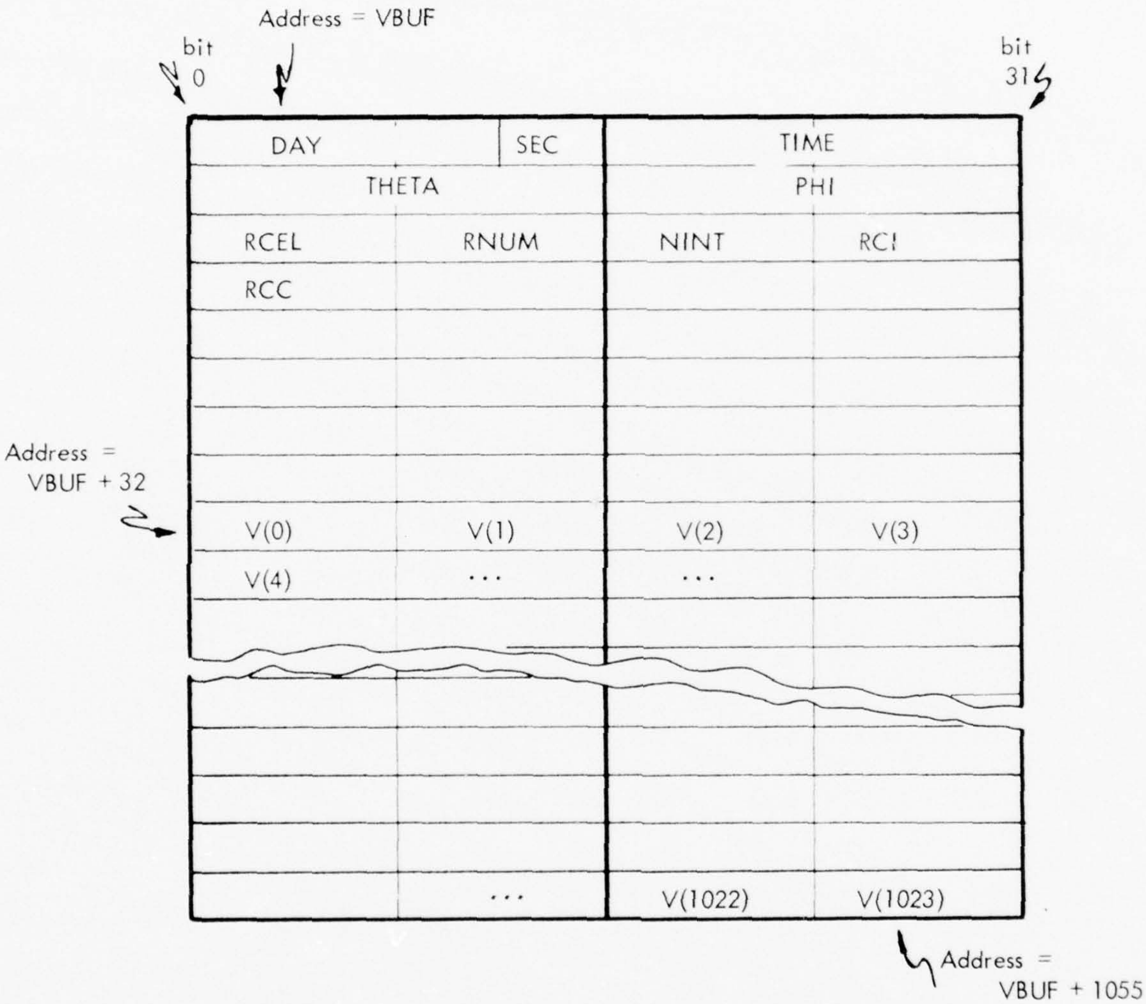

Figure 3-1. Video Buffer (VBUF)

VBUF is the table which contains the integrated video data and its associated radar ancillary data. If real-time data is being used, the video and integrator parameters come from the integrator and the date, time and antenna position come from the ancillary data port. If tape-recorded data is being used, all data comes from magnetic tape. The tape record is formatted just as VBUF. Units-seconds, a four-bit BCD value is stored as the least significant four bits of the second byte. This permits determination of time to the nearest ten seconds by examination of only the second half word of the table.

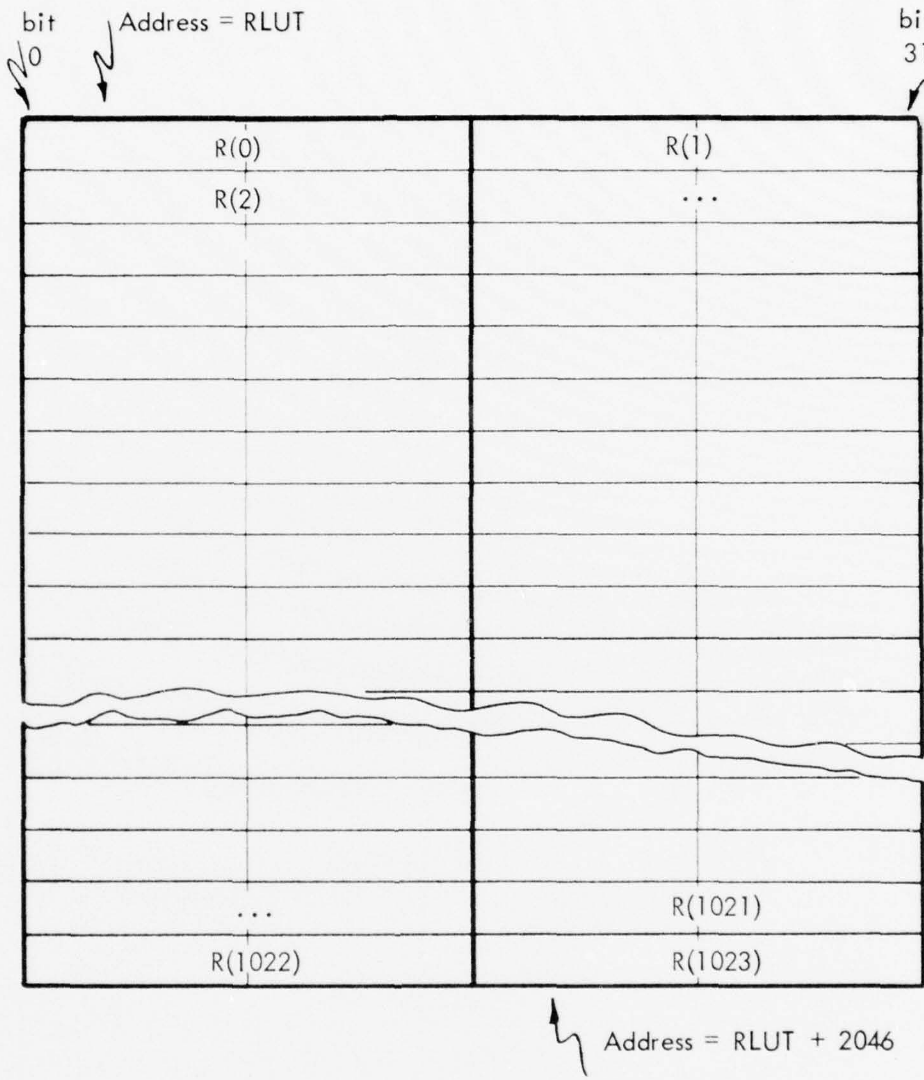

Figure 3-2. Range Look-Up Table (RLUT)

RLUT is a look-up table which identifies the range-cell number which lies on the rocket trajectory, as a function of radar antenna elevation angle. There are 1024 possible antenna elevation angles, PHI, and a maximum of 1024 radar range cells. Each R(PHI) is therefore a ten-bit value.

$$R(PHI) = DR/(\cos(PHI) - \sin(PHI) \cdot \cot(PHIT))$$

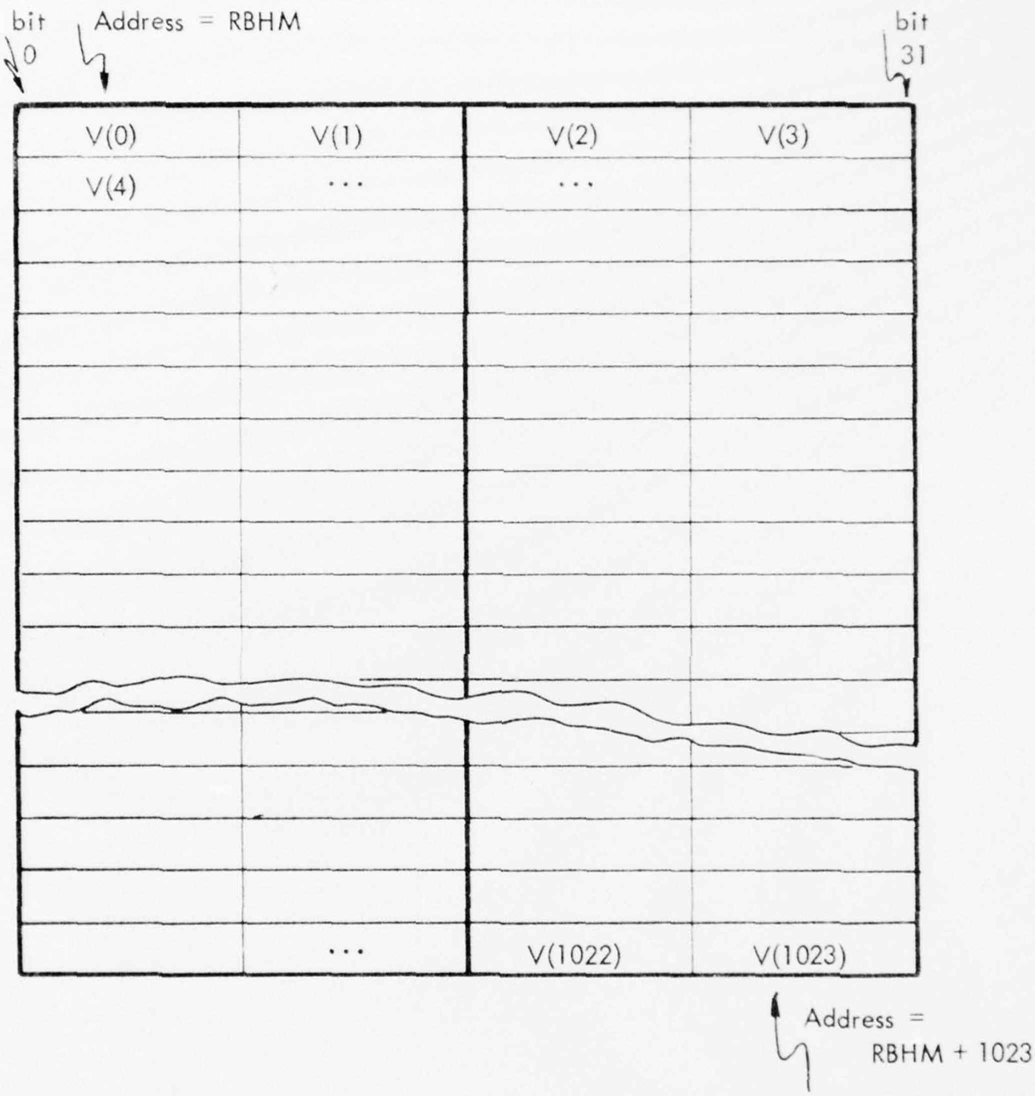

Figure 3-3. Range Cells Beyond HM (RBHM)

RBHM is a table containing the integrator (tape) video output, for all range cells associated with the integration period at the maximum antenna elevation angle.

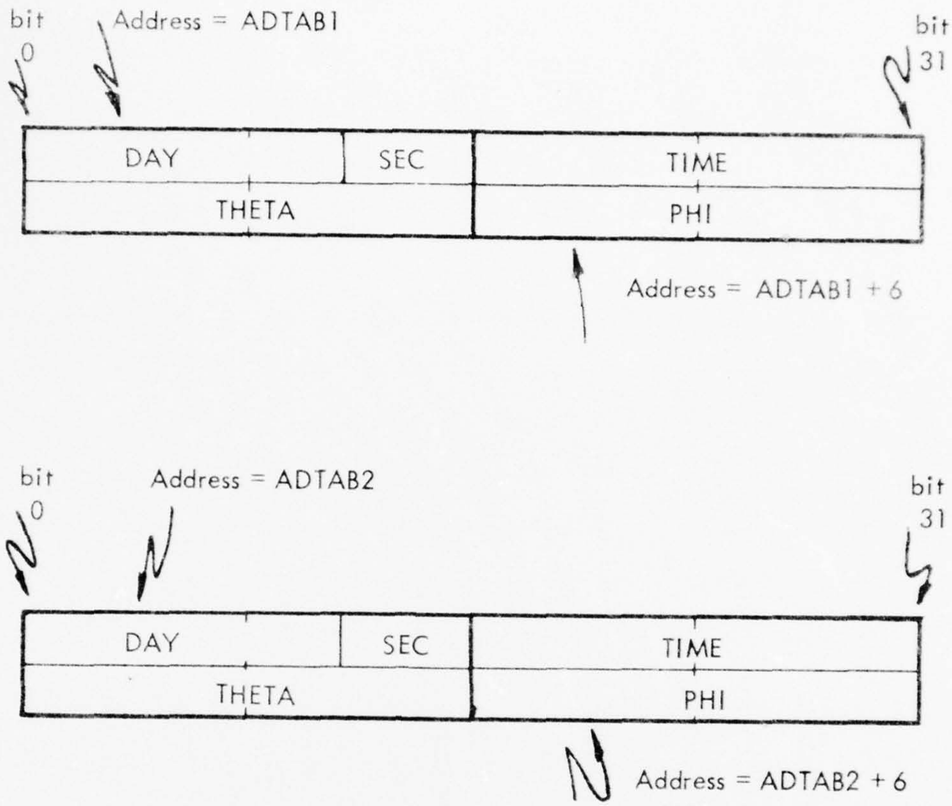

Figure 3-4. Ancillary Data Tables

The ancillary data tables contain the radar ancillary data associated with the integration periods occurring at the maximum and minimum elevation angles. Data is transferred to ADTAB1 at the first antenna turn-around point and to ADTAB2 the second time the antenna scan direction changes. Units-seconds, a four-bit BCD value, is stored as the least significant four bits of the second byte in each case.

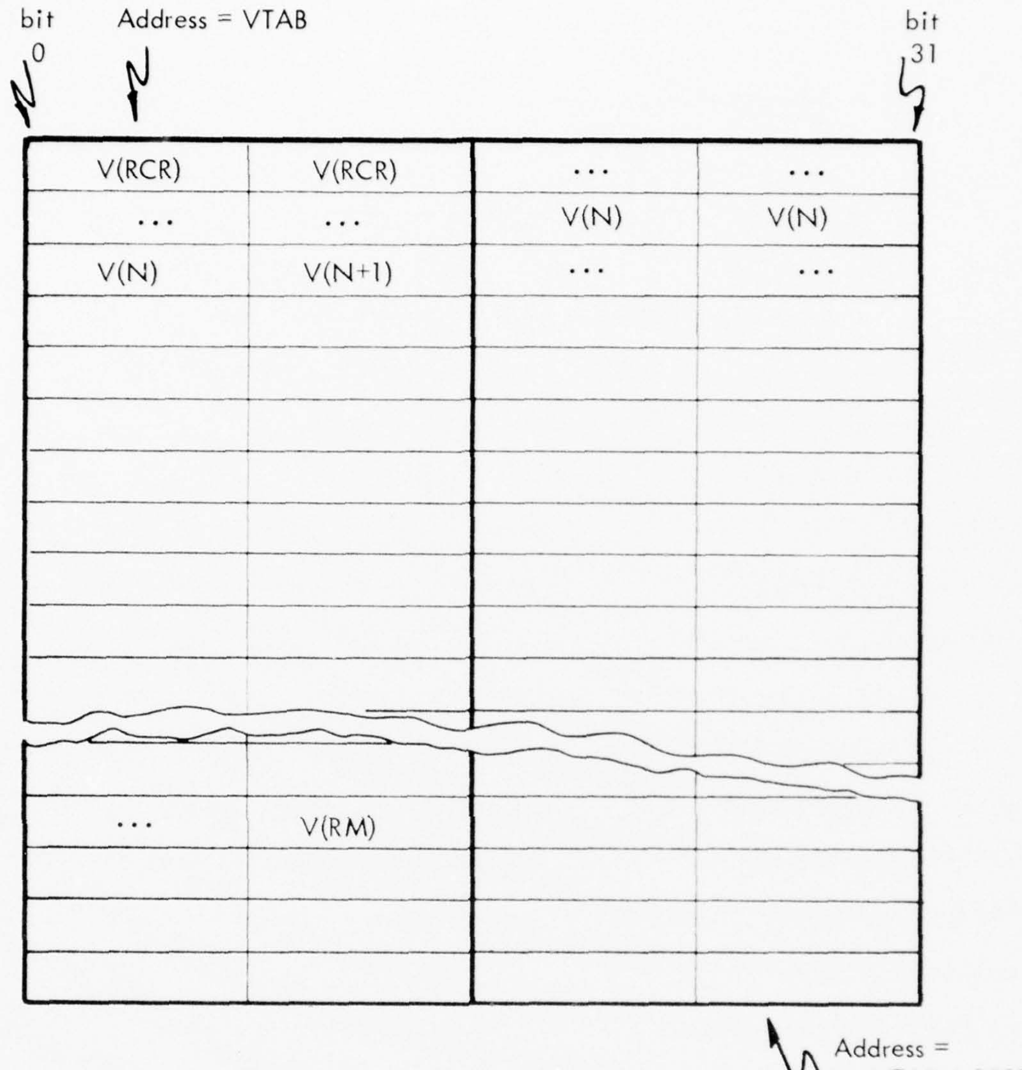

Figure 3-5. Video Table (VTAB)

VTAB is a table of selected values of integrated radar video. The selected values are stored in VTAB in an altitude ordered and indexed manner. The index for storage into VTAB is computed as the range-cell number times the sine of the elevation angle times eight. (This index is related to altitude as follows: Altitude = Index * Range cell size/8). The range cell values chosen for placement in VTAB are chosen on the basis of range-cell intersection with or proximity to the rocket trajectory. The determination of the appropriately ranged video was made by reference to RLUT after each integration period.

The range values chosen for the beginning table entries are the video values at the ground clutter range (RCR) if the radar range to the trajectory intersection is less than RCR.

The maximum index into VTAB is limited to 1599. This limit corresponds to a minimum altitude of 15 kilometers.

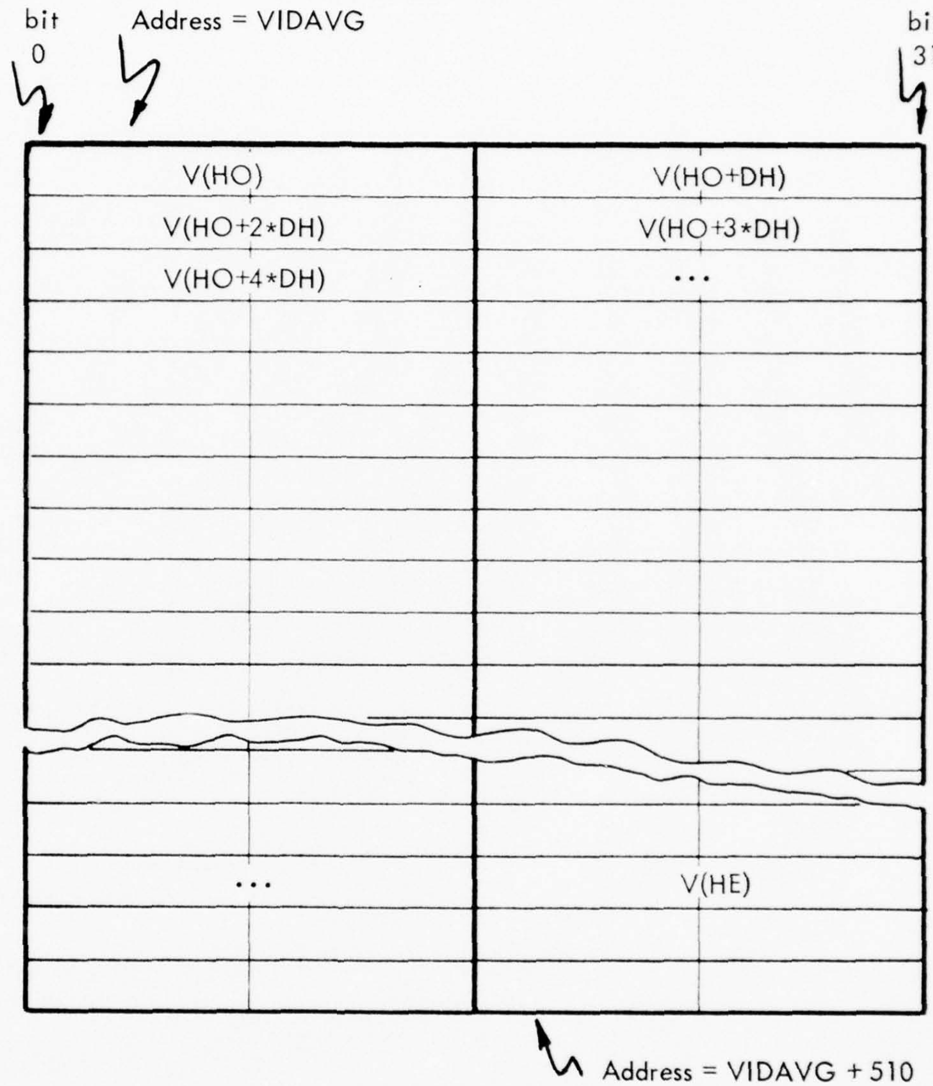

Figure 3-6. Averaged Video Table (VIDAVG)

VIDAVG contains averaged values of radar video for each of the altitude steps. The value of each table entry is between 0 and 511 (9-bits) and therefore each table entry requires 2 bytes.

The number of table entries is a function of the altitude quantization, DH, and the altitude extremes for which LWC will be calculated, HO and HE. The first entry would be the value for the first altitude quantization step above HO, the second entry will be for the second step, etc. The maximum number of entries will be 256.

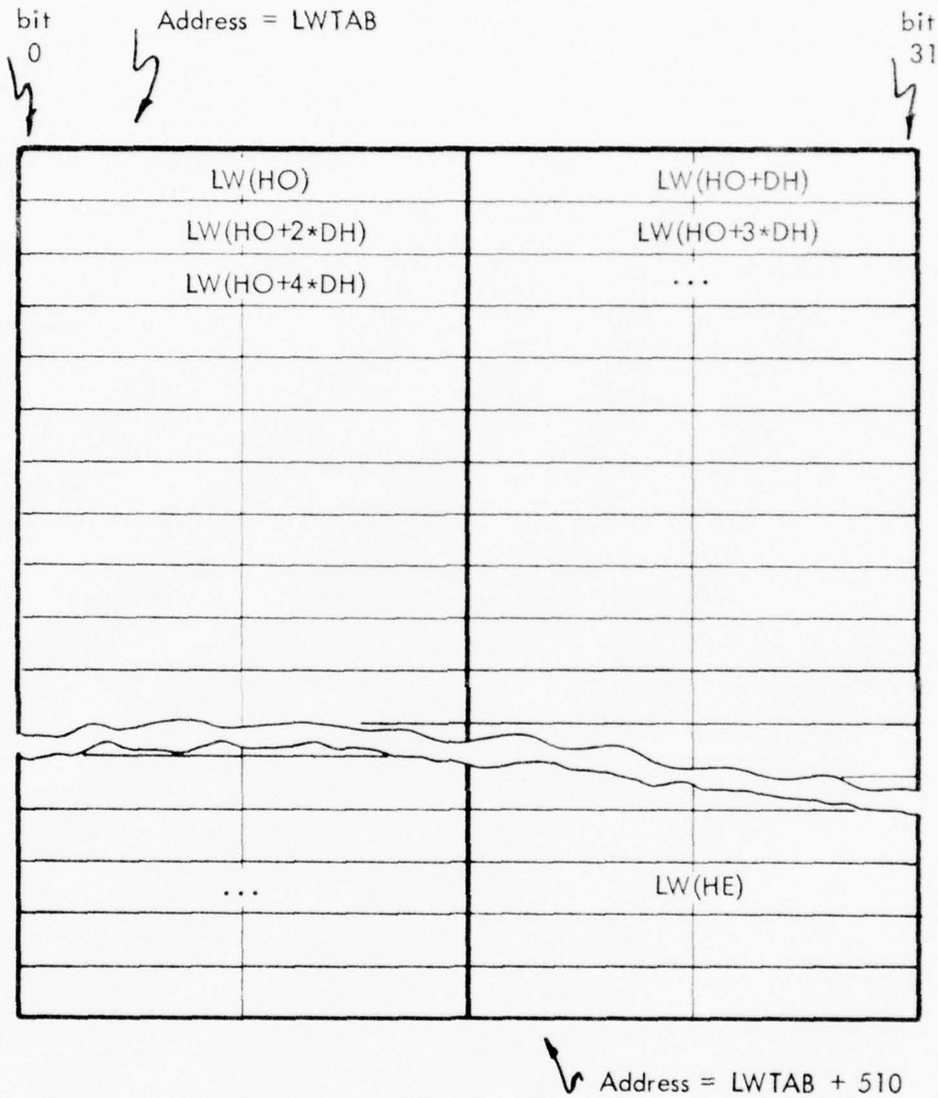

Figure 3-7. Logarithm of Liquid Water Content Density (LWTAB)

LWTAB contains scaled values of log-base-10 of the calculated liquid water content density (W). Value of LW(H) is between 0 and 255 to permit convenient output to the display.

The number of table entries is a function of the altitude quantization, DH, and the altitude extremes for which W was calculated, HO and HE. The first entry would be the value for the first altitude quantization step above HO, the second entry will be for the second step, etc. The maximum number of entries will be 256.

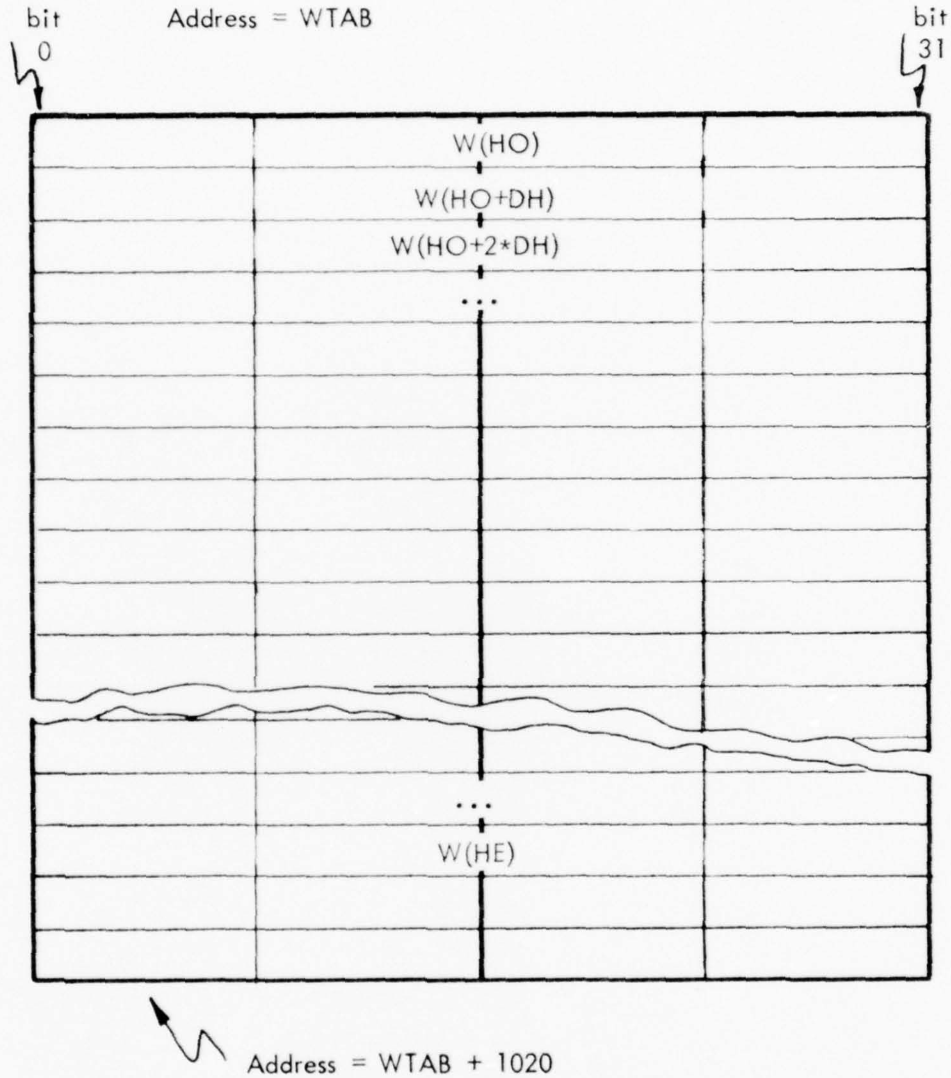

Figure 3-8. Water Content Table (WTAB)

WTAB contains the scaled values of liquid water content density. Each entry will occupy a full 32-bit word. The table entries will be indexed just as described in Figure 3-6 and 3-7; again the maximum number of entries will be 256.

SECTION 4. TELETYPE MESSAGES

All of the teletype messages and their purposes and appropriate operator responses are listed in Table 4-1. The messages are ordered and grouped as they might appear on the teletype machine. Some messages can appear only with others and these messages are grouped between double horizontal lines in the table, for example, all of the acquisition parameters become available for editing together and these messages are therefore grouped between double lines.

Table 4-1. Teletype Messages

Message	Purpose	Response
SYSTEM READY SELECT MODE OF OPERATION "REC", "PL", "LW", "HA"	Enables operator to select the basic program operating mode.	REC: Record only PL: Playback only LW: Liquid Water content analysis HA: Halt
SELECT INPUT MODE "TP", "RT"	Having chosen the LW mode of operation, permits choice of input source	TP: Magnetic tape input RT: Real time input from integrator
RECORD IN REAL TIME? "YES", "NO"	Having specified LW and RT, operator can choose to record the input data	YES: Record data NO: No recording of data
READY FOR DATA ACQUISITION SELECT "ACQ", "EDIT", "PARA", "ANA", "HALT"	After calculating parameters and table values required for acquisition, operator can select processing.	ACQ: Enter data acquisition phase EDIT: Edit acquisition or analysis parameters PARA: Print acquisition and analysis parameters ANA: Perform analysis on data in acquisition tables and output liquid water content plot and tables.
READY FOR ANALYSIS	When acquisition conditions have been satisfied, notifies operator that analysis can begin	None
TIME OF RECORDING DAY 105 TIME 121516	When the input mode is magnetic tape, operator is given the day and time of the recording. DAY is the Julian day of the year. Time is hours, minutes, seconds. Message is printed on the basis of the first tape record read after operator selects PL or LW and TP. If LW and TP, message is printed again at beginning of analysis phase on the basis of the most recently read tape record.	None
INTEGRATION PARAMETERS RCEL 1.0 RNUM 768 NINT 128 RCI 16 RCC 69	Integration parameters used during the recording of magnetic tape data. Message is printed on basis of data in the first tape record read after operator selects PL or LW and TP.	Operator should set the Integrator cell width equal to RCEL, number of cells equal to RNUM, SWEEPS INTEGRATED equal to 128 and CELLS INTEGRATED equal to 1. The Scan Conversion Processor RANGE CELL WIDTH should be set to RCEL.
END OF TAPE - UNABLE TO CONTINUE	Notifies operator that the magnetic tape recorder has sensed the end of the tape.	Program writes an EOF, rewinds the tape and initializes the system.
TAPE DEVICE UNAVAILABLE	Magnetic tape unit called for but not available.	If tape input called for or record only mode, initializes system. If LW, RT, record mode, continues without recording.

Table 4-1. (Continued)

Message	Purpose	Response
TAPE ERROR SELCT "GO", OR "HALT"	Parity error on tape. Program tries reading the record 10 times before giving up.	GO: Ignore error, pretend data is good. HA: Initialize the system.
ERROR	Notifies operator of a teletype input error.	Repeat input.
PRINTER PROBLEM	Notifies operator of line printer status error	Turn on, or select line printer. Program does not wait for correct status - it continues other processing.
SELECT EDIT TYPE "ACQ" OR "ANA"	After choosing to edit, permits operator to select either the acquisition or analysis parameters	ACQ: Acquisition parameters ANA: Analysis parameters
SELECT TRAJECT PARAMETERS DIS FROM RADAR TO LAUNCH SITE: NNNNNN METERS	Enables entry of launch site location	Distance in meters. CR will force use previous value
TRAJECTORY ANGLE: NN.NN DEGREES	Enables entry of launch trajectory angle	Angle above horizon in degrees. CR will force use previous value
SELECT RANGE OF CLUTTER: NNNNN METERS	Enables entry of range extent for ground clutter.	Range in meters. CR will force use previous value.
SELECT MAX ALT ALONG TRAJ: NNNNN METERS	Enables entry of maximum weather *altitude along the* trajectory (HM)	Altitude in meters CR will force use previous value.
HM TOO LARGE	Notification that HM is beyond the range of the present radar integration parameters	Program substitutes largest possible value.
START ALTITUDE: NNNNN METERS	Enables operator to specify minimum altitude of interest for analysis	Altitude in meters (Program calculates minimum possible altitude during analysis and substitutes new minimum if necessary) CR will force use of previous value
STOP ALTITUDE: NNNNN METERS	Enables operator to specify the maximum altitude of interest for analysis	Altitude in meters (Program calculates maximum possible altitude during the analysis phase and substitutes new maximum if necessary) CR will force use of previous value.
SELECT CALIBRATION CONSTANT NN	Permits entry of new radar calibration constant	Enter constant in dB. CR will force use of previous value.
ALTITUDE STEP SIZE: NNNNN METERS	Permits entry of altitude step size	Enter step size in meters CR will force use of previous value.
1ST TRANSITION: NNNNN METERS	Permits entry of first transition altitude	Enter transition altitude in meters CR will force use of previous value.
2ND TRANSITION: NNNNN METERS	Permits entry of nominal second transition altitude	Enter transition altitude in meters CR will force use of previous value.

Table 4-1. (Continued)

Message	Purpose	Response
2ND TRANSITION REFLECTIVITY: NN DB	Permits entry of maximum reflectivity for second transition region.	Enter reflectivity in dB Z. CR will force use of previous value.
3RD TRANSITION: NNNNN METER	Permits entry of nominal third transition altitude	Enter transition altitude in meters CR will force use of previous value.
3RD TRANSITION REFLECTIVITY: NN DB	Permits entry of maximum reflectivity for the third transition altitude	Enter reflectivity in dB Z. CR will force use of previous value.
TRANSITION 1 THICKNESS: NNNN METERS	Permits entry of first transition thickness	Enter thickness in meters CR will force use of previous value.
TRANSITION 2 THICKNESS: NNNN METERS	Permits entry of second transition thickness	Enter thickness in meters CR will force use of previous value.
TRANSITION 3 THICKNESS: NNNN METERS	Permits entry of third transition thickness	Enter thickness in meters CR will force use of previous value.
EXPONENT FOR RAIN: N.NN	Permits entry of rain related exponent	Enter exponent CR will force use of previous value.
LARGE SNOW:	Permits entry of large snow related exponent	Enter exponent CR will force use of previous value.
SMALL SNOW:	Permits entry of small snow related exponent	Enter exponent CR will force use of previous value.
ICE:	Permits entry of ice related exponent	Enter exponent CR will force use of previous value.
COEFFICIENT FOR RAIN: NNNNNN	Permits entry of rain related coefficient	Enter coefficient CR will force use of previous value.
LARGE SNOW:	Permits entry of large snow related coefficient	Enter coefficient CR will force use of previous value.
SMALL SNOW:	Permits entry of small snow related coefficient	Enter coefficient CR will force use of previous value.
ICE:	Permits entry of ice related coefficient	Enter coefficient CR will force use of previous value.
SELECT DISPLAY FOR PLOT: N	Permits entry of display number on which the liquid water content density versus altitude plot will be presented	Enter display number.
ALTITUDE EXTREMES: TO METERS	Informs operator of the altitude extremes for which there is data in the acquisition tables and for which analysis will be performed	None
REFLECTIVITY SPECIFIED FOR 2ND TRANSITION ALT IS TOO SMALL TRY AGAIN: NN DB	Informs operator that the maximum reflectivity specified for the second transition region is too small	Enter new transition reflectivity in dB Z.
REFLECTIVITY SPECIFIED FOR 3RD TRANSITION ALT IS TOO SMALL TRY AGAIN: NN DB	Informs operator that the maximum reflectivity specified for the third transition region is too small.	Enter new transition reflectivity in dB Z.

SECTION 5. PROGRAM MODULES

The complete computer program consists of eight (8) program modules. Each of these modules is assembled as a stand-alone program with references to common constants, variables, subroutines and entry points in other program modules established by a series of equate statements at the beginning of the program module. The functions performed by each of the individual modules are described in the following paragraphs. Table 5-1 lists all important subroutines and subprograms together with a brief description and access information. Table 5-1 begins on page 5-5.

5.1 Tables and Constants (TBL)

The first program module establishes the memory location and, if applicable, the initial value of all program constants and variables which are shared among the other seven program modules. In addition, two very short subroutines are included in this program modules: TTYERROR is a general purpose routine which simply prints ERROR on the teletype machine and then returns; TTYRCC is called to input the radar calibration constant from the teletype, convert the input to binary and store the converted and scaled constant for future use.

5.2 Executive (EXC)

The executive program module contains the routines for: 1) initialization of program flags and machine interrupts; 2) determination of processing mode; 3) the RECORD only mode; 4) the PLAYBACK only mode; 5) console display of the radar antenna azimuth and elevation; 6) the liquid water content holding position while waiting for specific analysis instructions; 7) the liquid water content data acquisition phase; 8) magnetic tape command generation and tape recorder status processing; 9) integration parameter acquisition, de-coding, storage and output to the teletype; 10) conversion of coded time-of-day to ASCII and its output to the teletype;

11) setting-up the scan direction flags for data acquisition; 12) arming the teletype for input command while performing other processing tasks; and 13) processing radar input/output interface errors.

The entry points from other program modules are INIT1 for re-initialization; ACQCHECK, the LWC analysis mode holding looping; and TIMETTY for converting the coded time-of-day to ASCII and outputting it to the teletype.

5.3 Edit (EDT)

The edit program module contains all the processing associated with the input of the acquisition and analysis parameters used for liquid water content analysis. There are three program entry points; ANAEDIT is the entry point for editing the analysis parameters, LW2 is the entry point for editing the acquisition parameters and LW2D2 is the entry point for rebuilding the tables and re-computing variables that depend on launch trajectory parameters.

5.4 Analysis (ANL)

The analysis program module calculates the liquid water content density along the trajectory on the basis of the radar data saved in VTAB during data acquisition and the analysis parameters. There is a single-entry point (ANALYSIS) and the exit is to the output program module (ANAPLT) which outputs the calculated analysis values.

5.5 Subroutines (SUB)

Seven major program subroutines which are called from the other program modules are contained in the subroutine program module.

BCDASC is a subroutine used to convert binary-coded decimal (BCD) numbers to their equivalent ASCII code so they can be output to the teletype or line printer.

The subroutine ASCBIN converts a string of ASCII numbers to a single binary (full word) equivalent. The binary equivalent is scaled up (multiplied) by a factor equal to ten to the number of digits to the right of a decimal point.

Subroutine BINASC converts a binary full word input to a string of ASCII numbers. If the input is negative, the most significant ASCII character is a minus sign; if the input is positive, the most significant ASCII character is the most significant digit.

The subroutines CROT and CVEC are circular CORDIC subroutines used to compute trigonometric functions and to do vectoring. See Appendix A.

The teletype driver, TTYIO, is also included in the subroutine package. This subroutine handles all teletype input and output on an interrupt serviced basis.

The subroutine FINISH is used to end the recording process, and write an end-of-file (EOF) on the magnetic tape. Control is return to the initialization routine, INIT1, in the executive module.

5.6 Magnetic Tape Driver (TAP)

The magnetic tape driver program module is devoted exclusively to handling input and output for the magnetic tape recorder. There are unique driver commands for output, input, write EOF, rewind, search for EOF, and backspace. Since the magnetic tape recorder is a 7-track machine and the computer memory is 8-bit oriented, the data to and from the tape recorder must be unpacked and packed to achieve maximum tape utilization and to insure no loss of data; the packing and unpacking routines are included as part of the magnetic tape driver.

5.7 Radar I/O Drivers (RDR)

The radar I/O driver program module contains the subroutines for the input and output of radar video and ancillary data. Video data are passed to and from the computer across an interface with the integrator. Ancillary data (date, time, antenna azimuth and elevation angles) are exchanged through an interface directly with the scan converter/refresh memory system. Video data input and output are handled by subroutines VIDINP and VIDOUT, respectively; ancillary data input and output are handled by ANCINP and ANCOUT, respectively. See Appendix G for more details.

5.8 Output (OUT)

Special output routines for liquid water content data are included as part of the output program module. The primary entry point is to ANAPLT. This entry is used when the results of liquid water content analysis are to be plotted and printed in tabular form. The routine for printing all of the system acquisition and analysis parameters is also part of this program module. This routine (DIPARM) is called by entry to ANAPLT but may be called directly so that the parameters can be inspected before acquisition, analysis or editing.

Table 5-1. Subprograms

NAME	MODULE	DESCRIPTION	CALLING SEQUENCE/RETURN
ACQ	EXC	The video data to be used in the calculation of liquid water content is acquired and put in to table VTAB by this subroutine. Criteria for determining which data are to be saved in VTAB are based on the antenna elevation angle, and the launch trajectory parameters.	Called by ACQCHECK; exits back to ACQCHECK if recording or goes to ANALYSIS.
ACQCHECK	EXC	A holding loop used in the LW mode of operation to wait for data acquistion to begin or for other TTY command.	Called by any branch to ACQCHECK; return is to ACQ, EDITCHECK, FINISH, ANALYSIS, DIPARM
ALTCOMP	ANA	Computes the altitude of an acquisition data point based on the table address of the point and the launch/acquisition geometry.	Called by ANALYSIS
ANA8 ANA9 ANA10 ANA11 ANA12	ANA	Compute H1, H2, H3 in units of DH. H2 and H3 are a function of Z2 and Z3 in addition to H12 and H13 respectively	Called by ANALYSIS
ANA13	ANA	Computes number of DH steps across each transition region.	Called by ANALYSIS
ANAEDIT	EDT	Requests input of the analysis parameters; no input results in use of the last used parameter. Analysis parameters requested are DH, HI1, HI2, Z2INP, H13, Z3INP, T1, T2, T3, S1, S2, S3, S4, Q1, Q2, Q3, Q4, and DISNUM. After receipt of new inputs the table RLUT is created and control is transferred back to ACQCHECK	Called by EDITCHECK; exits to LW2D2 to create new table RLUT and then back to ACQCHECK.
ANAER1 ANAER2	ANA	Error routines for H2 and H3 calculations.	Called by ANA9 and ANA11
ANALYSIS	ANL	A stand alone subprogram which averages the acquired video over increments of DH and then on the basis of the analysis parameters calculates liquid water content (W) density and log of the liquid water content density as a function of altitude between the altitude extremes HO and HE. Averaged video is left in table VIDAVG, log of W is left in LWTAB, and W is left in WTAB.	Called by ACQCHECK and ACQ; exits to ANAPLT.
ANAPLT	OUT	A stand alone subprogram which takes the data tables established by ANALYSIS and outputs these data to the line printer and display.	Called by ANALYSIS; calls LWCPLT, PRTOUT, DIPARM; exits to ACQCHECK.

Table 5-1. (Continued)

NAME	MODULE	DESCRIPTION	CALLING SEQUENCE/RETURN
ANCER VIDER	EXC	Error routines for radar driver subroutines. Output message and error code. (See VIDINP, VIDOUT, ANCINP, ANCOUT)	Called by error return from ANCINP, VIDINP, ANCOUT, VIDOUT
ANCINP	RDR	Ancillary data port input interface driver. GET DAY, TIME, THETA and PHI from Scan Converter into VBUF. Interface error returns to error return address with error code in register 10 as follows: 0 no error 1 no interrupt occurred between requests 2 inputs (outputs) were all zeros. Also see appendix	Called by: BAL 13, ANCINP DC Z (Error return address) Normal return by B 2(13)
ANCOUT	RDR	Ancillary data port output interface driver. Outputs DAY, TIME, THETA and PHI to Scan Converter from VBUF. Error return codes the same as ANCINP	Called by: BAL 13, ANCOUT DC Z (Error return address) Normal return by: B 2(13)
ASCBIN	SUB	Convert a string of ASCII numbers to a single full word binary equivalent. Binary equivalent is scaled up by a factor of ten times the number of characters to the right of the decimal point.	Called by: BAL 15, ASCBIN DC Z (input address) DC Z (output address) DC Z (error return address) DB N, N (number of characters to the left and right of the decimal point) Returns by: B 8(15)
BCDASC	SUB	Converts a string BCD numbers to their 7-bit ASCII code equivalent	Called by: BAL 15, BCDASC DC Z (INPUT ADDRESS) DC Z (OUTPUT ADDRESS) DC H'NUMBER OF DIGITS' Returns by: B 6(15)
BINASC BINASC1	SUB	Converts binary full word input to ASCII characters. Puts LSB at output address, LSB+1 at output address -1, etc. If input is negative, most significant output character is minus sign Returns character count as binary half word to address in register 15 plus 4.	Called by: BAL 15, BINASC DC Z (input address) DC Z (output address) DS 2 Returns by: B 6(15)
CROT	SUB	Performs CORDIC rotation to find sine and cosine of angles.	See Appendix A
CVEC	SUB	Performs CORDIC vectoring	See Appendix A

Table 5-1. (Continued)

NAME	MODULE	DESCRIPTION	CALLING SEQUENCE/RETURN
DIPARM	OUT	Outputs acquisition and analysis parameters to the line printer.	Called by ACQCHECK and ANAPLT; returns to calling program.
DISANGLE	EXC	Displays Hex representation of THETA and PHI on the display panel.	Called by RECORD, PLAYBACK, and all LW modes.
EDITCHECK	EXC	Determines which of the input parameters are to be edited.	Called by ACQCHECK; exits to LW2 which edits the acquisition parameters or ANAEDIT which edits the analysis parameters. Both LW2 and ANAEDIT return to ACQCHECK by way of LW2D2.
FINISH	SUB	Closes open tape file and returns to INIT1.	Called by entering 'HA' on teletype
HROT HVEC	ANL	These hyperbolic CORDIC subroutines are used by LWC for evaluation of natural logs and anti-logs.	Called by LWC; returns to LWC.
ILLIN IMAML IARFL	EXC	Processors for computer internal interrupts, illegal instruction (1), machine malfunction (2), and arithmetic fault (3), respectively. All will halt computer displaying location of fault and fault type on display panel. Registers are not changed. Machine is left ready to re-start from wherever it was.	Called by internal interrupt.
INIT1	EXC	An initializing routine used to clear flags and request via TTY operating mode instructions	Called by any branch to INIT1; return is to RECORD, PLAYBACK, LW1A, or FINISH
INTERPOL	ANA	Computes interpolation increments for exponents and coefficients for each of the transition regions.	
LW1A	EXC	Determines whether input for LW analysis will be real time data or magnetic tape.	Called by INIT1; exits to LW1B to set up for real time data input or LW1C to set up for magnetic tape input. Both LW1B and LW1C exit to LW2D2 for table RLUT construction and then to ACQCHECK.
LW2	EDT	Requests input of the acquisition parameters; no input results in use of the last used parameter. Acquisition parameters requested are DIS, PHIT, RCM, HM, HO and HE.	Called by EDITCHECK; exits to LW2D2 to recalculate geometry constants and table and then returns to ACQCHECK.
LW2D2	EDT	Establishes the constants and table based on the geometry of the launch, integrator parameters and acquistion parameters. Calculates CPHIT, SPHIT, COPHIT, HMR, DR, RCR, GR, RM, RLUT, PHIMAX	Called by LW1A, ANAEDIT, LW2; exits to ACQCHECK

Table 5-1. (Continued)

NAME	MODULE	DESCRIPTION	CALLING SEQUENCE/RETURN
LWC	ANL	Analytical subroutine to calculate liquid water content (W) on the basis of radar reflectivity (video) and a phase related coefficient and exponent (Q and S). See appendix D.	Called by BAL 8, LWC; uses video from register 3, exponent (S) from register 4, and coefficient (Q) from register 5. Returns to address in register 8 and leaves 1000 times liquid water content (1000*W) in register 7 and (log W + 3) 2**12 in register 6.
LWCPLT	OUT	Plots the logarithm of liquid water content density versus altitude on one of the scan converter displays.	Called by ANAPLT; returns to ANAPLT.
PARBIN	EXC	Converts integrator parameter codes to binary values.	Called by: BAL 15, PARBIN Returns by: BR 15
PARTTY	EXC	Converts integrator parameters from binary to ASCII and outputs them to the teletype.	Called by: BAL 14, PARTTY Returns by: BR 14
PLRETAPE	EXC	Routine to read or write magnetic tape into or out of VBUF.	Called by RECORD, PLAYBACK and all LW modes.
PRTOUT	OUT	Outputs a string of characters to the line printer.	Called by: BAL 15, PRTOUT DC H' number of characters' DC Z (address of character strings) Returns by: B 4(15)
RECORD	EXC	Routine used for the 'record only' mode of operation. Get the radar calibration constant, integrator parameters, video data, and ancillary data and then proceeds to record these data until it runs out of tape or is HALTED by means of teletype input.	Called from INIT1; Calls TTYRCC, SCIPAR, VIDINP, ANCINP, PLRETAPE, DISANGLE and TTYIN.
SCIPAR	EXC	Inputs integrator parameters RCEL, RNUM, NINT, RCI and stores binary codes into VBUF.	Called by: BAL 15, SCIPAR Returns by: BR 15
SCNDIR	EXC	Set up Scan direction flags for ACQ. DAQFLG (BYTE) = 0; initial condition 1;called once 2; called two or more times DAQFLG1+1 (BYTE) = 1; one direction change 2; two direction changes DAQFLG2 (BYTE) = 1; PHI increasing = 0; PHI decreasing	Called by: BAL 15, SCNDIR Returns by: BR 15

Table 5-1. (Continued)

NAME	MODULE	DESCRIPTION	CALLING SEQUENCE/RETURN
TAPEIO	TAP	Magnetic tape recorder input/output driver. Also performs packing and unpacking for 7 track tape unit.	Called by: BAL 15, TAPEIO DC X '(request code)' DC H '(number of half words)' DC Z (starting address) Tape recorder status (byte) returned to address in register 15+1. Bit 0 at the address in register 15 is set while tape operation is in process. Returns to address following last calling parameter. Request code: 00 = Output 10 = Input 20 = Write EOF 30 = Rewind 40 = Search EOF 50 = Backspace
TIMETTY	EXC	Converts the time of a data record from the coded time code generator output to ASCII and outputs to the TTY.	Called by BAL 14, TIMETTY; returns BR 14.
TPUNAV	EXC	Subroutine to handle a call to PLRETAPE when the mag tape recorder is unavailable. Puts out message on TTY; if not in LW mode, initialize system; if LW-TAPE, initialize system; if LW-REAL (RECORD), do analysis, if possible, otherwise initialize.	Called by PLRETAPE
TTYIO	SUB	Teletype input/output driver.	Called by: BAL 15, TTYIO DB N, M DC Z (Address) where N = 1 for input and 0 for output M = number of characters Address = address of input/output Returns by: B 4(15)
TTYERROR	TBL	Outputs the message 'ERROR' to the teletype followed by a carriage return, line feed.	Called by: BAL 14, TTYERROR Returns by: BR 14
TTYIN	EXC	Routine to arm teletype for input and allow other processing with ability to check for receipt of HALT or ANA.	Called initially by BAL 14, TTYIN Called for checking to see if input is ready by BAL 14, TTYIN1 Returns by BR 14
TTYINT	SUB	Interrupt entry point in teletype driver.	Teletype interrupt.

Table 5-1. (Continued)

NAME	MODULE	DESCRIPTION	CALLING SEQUENCE/RETURN
TTYRCC	TBL	Requests the radar calibration on the teletype; accepts RCC, converts to binary (RAWRCC) and scales to integrator units (RCCBIN)	Called by: BAL 13, TTYRCC Returns by: BR 13
VBUFRBHM	EXC	Moves all video data from VBUF to RBHM.	Called by: BAL 15, VBUFBRHM Returns by: BR 15
VIDINP	RDR	Interrupt serviced input interface driver for the precision digital video integrator. Inputs the number of processed range cells (RNUMBIN) and puts them in order beginning at VBUF+32. In the event of an interface error, returns to error address with error code in register 10 as follows: 0 no error 1 no start - timeout 2 no stop - time out 3 ESELCH status non-zero, memory error 4 buffer not completed - abnormal end 5 ESELCH hung busy to start Also see appendix	Called by: BAL 13, VIDINP DC Z (Error return address) Normal returns by: B 2(13)
VIDOUT	RDR	Interrupt serviced output interface driver for the integrator. Outputs the number of processed range cells (RNUMBIN) from VBUF+32 to the integrator. Error codes the same as VIDINP. See appendix.	Called by: BAL 13, VIDOUT DC Z (Error return address) Normal returns by: B 2(13)

APPENDIX A

Circular CORDIC Subroutines

RAYTHEON

FORM 10-0557 (9-65) BOND

DIVISION	Equipment	Classification	Unclassified
Operation	EDL	Contract No.	DNA001-75-C-0050
Department	ADL	Distribution	As Listed
To	J. H. Turner, Jr.	File No.	-
From	A. J. Jagodnik, Jr.	Memo No.	AJJ-19
Subject	Circular CORDIC Subroutines for Liquid Water Content (LWC) Determination System	Date	11 February 1975

References: Listed at end of memo.

The CORDIC technique[1.-4.] for computing transcendental functions has been chosen for implementation of certain subroutines required in the LWC initialization and analysis phase software. The method is appealing because, by using simple add, subtract, shift, and compare operations which are available as computer instructions, the look-up table requirements are reduced dramatically over a pure look-up table approach. Compared to a series expansion method, CORDIC has a speed advantage[2.] and it calculates two functions simultaneously. Details of the algorithms are well-covered in the references[1.-4.] and will not be repeated here.

The CORDIC algorithms involve iterative operations among three registers X, Y, and Z in a process similar to that employed in successive approximation A/D converters. The schematic representations of Figure 1 show the functions which can be calculated by means of the two circular CORDIC subroutines, named CROT and CVEC. In the rotation mode, (CROT), operations are performed such that the Z (angle) register is driven toward zero, while in the vectoring mode (CVEC), the Y register is driven toward zero. The constant K_1 (≈ 1.65), sometimes called the stretch factor, is a function only of the number of iterations. The first two examples of applications which appear in Figure 1 involve straightforward evaluation of trigonometric functions. Example 3 demonstrates how the multiple input/output feature can be used to advantage in evaluating a more complex trigonometric expression. Note that after step b, register X contains the proper number for the input at step d. Similarly, after step d, register Z contains the required input for step f. In cases such as these, the numbers can simply be left in the registers even while other operations, such as the addition in step c, are executed.

The scaling for sine, cosine and angle quantities in the LWC software has been established as described in reference 5. The sine and cosine are scaled alike and contain 15 significant bits such that a real-world value of unity corresponds to 32768 (Y'8000') in the Interdata 7/32 computer. The angle is scaled so that 90 degrees is represented as 1024 (Y'400'). The consensus of references 1 thru 4 is that for 15-bit accuracy, 19-bit registers and 16 iterations are required. The entire 32 bits of the general purpose registers could have been used, but in order to ensure at least 19 bits for accuracy while allowing capability for numbers much larger than those scaled like sines and cosines, the following arrangement has been adopted. The X and Y registers are shifted left 5 places and the Z is shifted 10 places before the algorithm is executed. After completion, the registers are shifted back a like number of places. Considering the stretch factor, inputs to X and Y should be kept to numbers within $\pm 2^{25}$ to avoid overflowing the registers. Inputs to X and Y can be scaled arbitrarily (what goes in comes out multiplied by K_1), but numbers which are smaller than those scaled like sines and cosines result in increased algorithmic errors.

Inputs to the Z register must be scaled properly since the look-up table for $\tan^{-1} 2^{-i}$ used in CROT and CVEC has predetermined scaling. The algorithms will work for values of Z over a range of about $\pm$ Y'470' ($\pm 99.8^\circ$). Outside of this range, CROT "limits"--it outputs the numbers corresponding to the nearest extreme. To prevent overflow of the Z register, keep inputs within $\pm 2^{21}$.

The CAL assembly listing for CROT and CVEC has been included as Figure 2. It would have been possible to code CROT and CVEC as one program with its mode controlled by a flag since they differ only in the test on Z or Y, but to conserve execution time, it was decided to generate two separate subroutines. They do, however, share the arctangent look-up

table CALFAT. Execution time has been estimated at 588 microseconds for either routine. Note that the location counter save register to be used with the BAL instruction is F, while the I/O registers are B, C and D. In addition, registers 7 thru A are used internally and should be saved, if required, before CROT or CVEC is called.

Both subroutines were run under OS32/ST with a simple driver added to generate $1/K_1$, load the X, Y and Z registers, and execute the BAL instruction. The registers were examined through the hex display console after each of a number of tests. CROT and CVEC performed as expected.

References

1. "The Cordic Trigonometric Computing Technique," J. E. Volder, IRE Trans. on Electronic Computers Vol. EC-8, No. 3, pp. 330-334, September 1959.
2. "CORDIC Technique Reduces Trigonometric Function Look-Up," Michael D. Perle, Zwicker Electric Co., N. Y., N. Y., Computer Design, June 1971.
3. "CORDIC Rotation Technique," J. S. Friedman, technical memo EM74-0542, JSF:74:01, dated 9 August 1974.
4. "A Unified Algorithm for Elementary Functions," J. S. Walther, Hewlett-Packard Co., Spring Joint Computer Conference, 1971.
5. "Liquid Water Content (LWC) Constants/Variables/Tables," J. H. Turner memo JHT:75:27, dated 26 January 1975.

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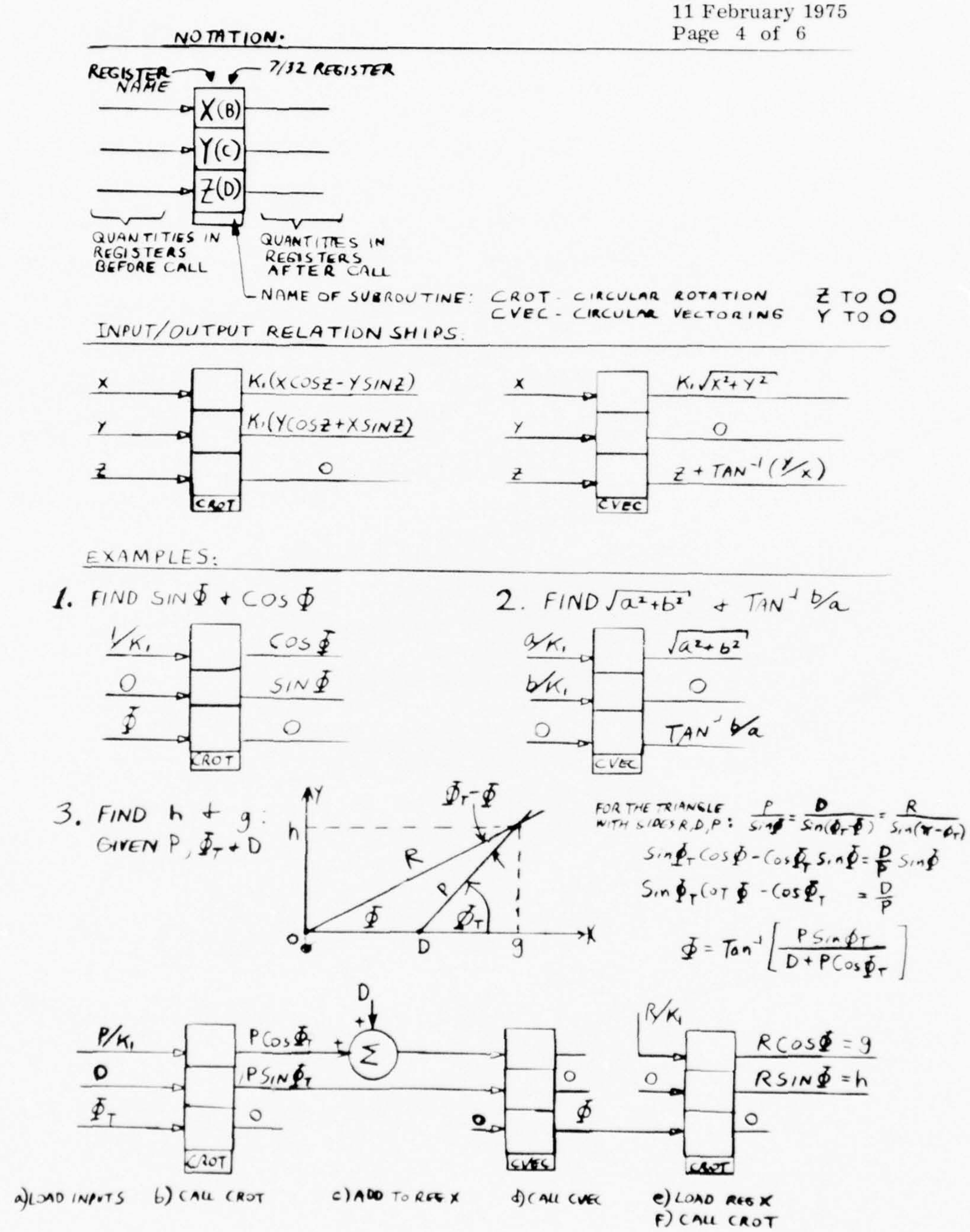

Figure 1. Circular CORDIC Input/Output Relationships and Examples of Applications

```
CROT/CVEC   7FEB75                                   PAGE   1

                                         SCRAT
                                         TARGT   32
                                         WIDTH   120
                                         FPAUS
           0000 000F         LCS         EQU     15           LOCATION CTR SAVE
           0000 0007         XS          EQU     7
           0000 0008         YS          EQU     8
           0000 0009         AR          EQU     9
           0000 000A         I           EQU     10           INDEX
           0000 000B         X           EQU     11           X I/O REG
           0000 000C         Y           EQU     12           Y  "   "
           0000 000D         Z           EQU     13           Z  "   "
000000I    24A0              CROT        LIS     I,0
000002I    EDB0 0005                     SLL     X,5          RESCALE
000006I    EDC0 0005                     SLL     Y,5          INPUT
00000AI    EDD0 000A                     SLL     Z,10         REGISTERS
00000EI    087B              AGAINC      LR      XS,X         X IN XS
000010I    088C                          LR      YS,Y         Y IN YS
000012I    EE7A 0000                     SRA     XS,0(I)      SHIFT XS RIGHT I PLACES
000016I    EE8A 0000                     SRA     YS,0(I)      "   YS   "    "    "
00001AI    11A2                          SLLS    I,2          MULT I BY 4
00001CI    589A 4000 00B8I               L       AR,CALFAT(I) GET ALFA
000022I    10A2                          SRLS    I,2          DIVIDE I BY 4
000024I    F9D0 0000 0000                CI      Z,0          COMPARE Z WITH 0
00002AI    4210 4000 003CI               BTC     1,CCWC       IF Z LT 0, GTO CCWC
000030I    0BB8                          SR      X,YS         CW
000032I    0AC7                          AR      Y,XS         ROTATION
000034I    0BD9                          SR      Z,AR
000036I    4300 4000 0042I               B       ITSTC        GTO ITSTC
00003CI    0AB8              CCWC        AR      X,YS         CCW
00003EI    0BC7                          SR      Y,XS         ROTATION
000040I    0AD9                          AR      Z,AR
000042I    26A1              ITSTC       AIS     I,1          INCREMENT I
000044I    F9A0 0000 0010                CI      I,16
00004AI    4210 FFC0                     BTC     1,AGAINC     IF I LT 0, GTO AGAINC
00004EI    EEB0 0005                     SRA     X,5          RESCALE
000052I    EEC0 0005                     SRA     Y,5          OUTPUT
000056I    EED0 000A                     SRA     Z,10         REGISTERS
00005AI    030F                          BR      LCS          RETURN TO MAIN PROGRAM
                             *IN CVEC, ONLY COMMENTS WHICH DIFFER FROM CROT ARE LISTED
00005CI    24A0              CVEC        LIS     I,0
00005EI    EDB0 0005                     SLL     X,5
000062I    EDC0 0005                     SLL     Y,5
000066I    EDD0 000A                     SLL     Z,10
00006AI    087B              AGAINV      LR      XS,X
00006CI    088C                          LR      YS,Y
00006EI    EE7A 0000                     SRA     XS,0(I)
000072I    EE8A 0000                     SRA     YS,0(I)
000076I    11A2                          SLLS    I,2
000078I    589A 4000 00B8I               L       AR,CALFAT(I)
00007EI    10A2                          SRLS    I,2
000080I    F9C0 0000 0000                CI      Y,0
000086I    4310 4000 0098I               BFC     1,CCWV       IF Y GE 0, GTO CCWV
00008CI    0BB8                          SR      X,YS
00008EI    0AC7                          AR      Y,XS
000090I    0BD9                          SR      Z,AR
```


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```
CROT/CVEC    7FEB75                                         PAGE   2

000092I  4300 4000 009EI     57              B       ITSTV
000098I  0AB8                58  CCWV        AR      X,YS
00009AI  0BC7                59              SR      Y,XS
00009CI  0AD9                60              AR      Z,AR
00009EI  26A1                61  ITSTV       AIS     I,1
0000A0I  F9A0 0000 0010      62              CI      I,16
0000A6I  4210 FFC0           63              BTC     1,AGAINV
0000AAI  EEE0 0005           64              SRA     X,5
0000AEI  EEC0 0005           65              SRA     Y,5
0000B2I  EED0 000A           66              SRA     Z,10
0000B6I  030F                67              BR      LCS
                             68  *THE FOLLOWING TABLE CONTAINS TAN**-1(2**-I) IN DEG*(2**19)/45
0000B8I                      69              ALIGN   4
0000B8I  0008 0000           70  CALFAT      DC      F'524288',F'309505',F'163534',F'83012'
0000BCI  0004 B901
0000C0I  0002 7ECE
0000C4I  0001 4444
0000C8I  0000 A2C3           71              DC      F'41667',F'20854',F'10430',F'5215'
0000CCI  0000 5176
0000D0I  0000 28BE
0000D4I  0000 145F
0000D8I  0000 0A30           72              DC      F'2608',F'1304',F'652',F'326'
0000DCI  0000 0518
0000E0I  0000 028C
0000E4I  0000 0146
0000E8I  0000 00A3           73              DC      F'163',F'81',F'41',F'20'
0000ECI  0000 0051
0000F0I  0000 0029
0000F4I  0000 0014
0000F8I                      74              END

CROT/CVEC    7FEB75                                         PAGE   3

NO ERRORS
  ABSTOP     0000 0000
  ADC        0000 0004
  AGAINC     0000 000EI
  AGAINV     0000 006AI
  AR         0000 0003
  CALFAT     0000 00B8I
  CCWC       0000 003CI
  CCWV       0000 0098I
  CROT       0000 0000I
  CVEC       0000 005CI
  I          0000 000A
  IMPTOP     0000 00F8I
  ITSTC      0000 0042I
  ITSTV      0000 009EI
  LADC       0000 0002
  LCS        0000 000F
  PURETOP  → 0000 0000P
  X          0000 000B
  XS         0000 0007
  Y          0000 000C
  YS         0000 0008
  Z          0000 000D
```

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AJJ-19
11 February 1975
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APPENDIX B

Analytic Determination of Liquid Water Content

RAYTHEON

FORM 10-0557 (9-65) BOND

DIVISION Equipment
Operation EDL
Department ADL

To File

From J. H. Turner, Jr.

Subject Analytic Determination of Liquid Water Content

Classification Unclassified

Contract No. -

Distribution -

File No. -

Memo No. JHT:75:19

Date 20 January 1975
Revsion 1: 26 January 1975

The Liquid Water Content Determination System being developed under contract DNA 001-75-C-0050 will use the digitized log-video output from the Raytheon Model D-A11-R5 Precision Digital Video Integrator (PDVI) to derive liquid water content density (W) as a function of altitude. This derivation will be made on the basis of the following relationship:

$$Z = Q \cdot W^S$$

where

Z = radar reflectivity
W = liquid water content density
Q = phase related constant
S = phase related constant

During the data acquisition phase of the liquid water content determination, a table, VTAB, will have been established and will contain values of the log-video output for points along the rocket trajectory of interest. Through a process of coordinate transformation, the altitude, including a correction for earth curvature, will be determined for each of the table entries. The total altitude extent for table entries will be divided into altitude groups of a size, DH, be specified by the operator and then all values of radar video contained in a given group will be averaged to yield a single value of radar video which is representative for that altitude segment.

The digitized log-video output of the integrator is related to Z in the following manner:

$$10 \text{ Log } Z = V - RCC$$

where V = log-video and
RCC = the radar calibration

The relationship to be used for the determination of W is therefore,

$$V - RCC = \log Q + S \log W$$

therefore,

$$W = \log^{-1}\left[\frac{\frac{V - RCC}{10} - \log Q}{S}\right]$$

where as previously stated S and Q are constants related to the particular phase of the water.

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A total of four water phases will be considered: rain, large snow, small snow, and ice. The altitude at which these phase changes take place have been designated as follows:

H1	-	rain to large snow
H2	-	large snow to small snow
H3	-	small snow to ice.

The thicknesses of these phase change regions, centered on H1, H2, and H3, have been designated T1, T2, and T3 respectively. The values of Q and S to be used in the determination of W have been designated as follows:

Q1, S1 for rain
Q2, S2 for large snow
Q3, S3 for small snow and
Q4, S4 for ice.

The values for Q and S will be linearly interpolated across each of the transition regions, T1, T2 and T3. The interpolated values of Q and S will then be used in the determination of W.

The phase transition altitude, H1, will be determined by observation of the "bright-band" on the radar display and will therefore be input by the operator.

The phase transition altitudes, H2 and H3, will be derived as follows:

1. A minimum altitude at which the phase change can take place will be determined from radiosonde data and input by the operator, HI2, HI3.

2. A minimum value of radar reflectivity will also be determined and specified by the operator for each transition point, Z2, Z3.

3. The transition altitude H2 shall be that altitude above HI2 where the radar reflectivity is less than Z2.

4. The transition altitude H3 shall be that altitude above H3 where the reflectivity is less than Z3.

Table 1 lists the constants required for the determination of liquid water content, their definition and their input source. In cases where the source has been designated as both TTY and Display, the intent is to indicate either of these devices as input sources.

Table 1

LWC Determination Constants

Name	Definition	Source: Derived	TTY	Display	Integrator
Z	Radar reflectivity	X			
W	Liquid Water Content Density	X			
Q1, Q2, Q3, Q4	Phase related constant		X		
S1, S2, S3, S4	Phase related constant		X		
VTAB	Range ordered table of radar video.				X
V	Single range value of log-video				X
RCC	Radar calibration constant		X		
H1	Rain/large snow transition altitude.		X	X	
H2	Large snow/small snow transition altitude.	X			
H3	Small snow/Ice transition altitude.	X			
HI2, HI3	Minimum altitudes for H2 and H3.		X	X	
Z2, Z3	Minimum reflectivities for H2 and H3.		X		
T1	Thickness of the rain/large snow transition region centered on H1.		X	X	
T2	Thickness of the large snow/small snow transition region centered on H2.		X	X	
T3	Thickness of the small snow/ice transition region centered on H3.		X	X	
DH	Size of altitude groups.		X		
HO	Lowest altitude for which LWC is desired.		X		
HE	Highest altitude for which LWC is desired.		X		

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APPENDIX C

Range of Liquid Water Content

RAYTHEON

FORM 10-0557 (9-65) BOND

DIVISION	Equipment	Classification	Unclassified
Operation	EDL	Contract No.	-
Department	ADL	Distribution	cc
To	File	File No.	-
From	J. H. Turner, Jr.	Memo No.	JHT:75:26
Subject	Range of Liquid Water Content	Date	26 January 1975
		Revised:	1 September 1975

Reference:
1. JHT:75:19, "Analytic Determination of Liquid Water Content", dated Rev. 1--1/26/75.
2. JHT:75:20, "Analysis Phase Software, dated 1/20/75.
3. JHT:75:27, "LWC Constants/Variables/Tables", dated 1/26/75

This memorandum establishes the range of the variables used to determine liquid water content from the integrator output values of log-video. From these values, the range extent of W is then determined.

RCC shall be the Radar Calibration Constant such that

$$V - RCC = 10 \log Z$$

where V is the eight-bit integrator output (MSB = 50 dB) and Z is the radar reflectivity.

Example:

$$V = 68 \text{ dB } (1\ 0\ 1\ 0\ 1\ 1\ 1\ 0)$$

$$RCC = 48 \text{ dB}$$

$$Z = \log^{-1}\left(\frac{68 - 48}{10}\right)$$

$$= 100$$

From JHT:75:19, Revision 1,

$$W = \log^{-1}\left(\frac{\frac{V - RCC}{10} - \log Q}{S}\right)$$

where W is liquid water content in units of grams/m^3.

As per K. M. Glover of AFCRL (LYW) on 24 January 1975, the values of Q and S to be encountered in the operational environment are as follows:

$$100 \le Q \le 200,000$$

$$1.63 \le S \le 2.54$$

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The range of V is

$$0 \le V < 100$$

and the range of RCC is

$$0 \le RCC \le 99$$

The analytical range of W may now be determined as follows:

$$W = \log^{-1}\left(\frac{\frac{V - RCC}{10} - \log Q}{S}\right)$$

W is maximum when

$$\frac{\frac{V - RCC}{10} - \log Q}{S}$$

is maximum.

$$\therefore$$

$$W_{max} = \log^{-1}\left(\frac{\frac{V_{max} - RCC_{min}}{10} - \log Q_{min}}{S_{min}}\right)$$

$$= \log^{-1}\left(\frac{\frac{100 - 0}{10} - \log 100}{1.63}\right)$$

$$= 80905$$

$$W_{min} = \log^{-1}\left(\frac{\frac{-99}{10} - \log 200,000}{1.63}\right)$$

$$= 4.72 \times 10^{-10}$$

The range of W is therefore,

$$4.72 \times 10^{-10} \le W \le 80905$$

On the basis of practical considerations, this range can be reduced to

$$10^{-3} \leq W \leq 100$$

Such a range, 5 orders of magnitude, rules out the possibility of graphically representing W on a linear scale. A logarithmic scale will be used for plotting the values of W. The X-axis of the display will be divided into five decades for this purpose ranging from 10^{-3} to 100.

In terms of software this will mean the creation of a new table, LWTAB, which will contain values of log W to be used for display output.

So as to insure that all arithmetic manipulations will involve only integers, the following scaling will be accomplished in the course of the determination of log W and W:

1. ~~The quantity, V - RCC, is constrained to be greater than or equal to zero.~~
2. The quantity, V - RCC, will be multiplied by 100 prior to division by 10; i. e., multiplied by 10.
3. The quantity calculated by steps 1 and 2 above will be increased by the addition of three (3) times the stored value of S. (The stored value of S is 100 times the real world value of S. See reference 3.)
4. The quantity, log Q, will always be positive due to the permissible range of Q (400 - 200, 000) and will be multiplied by 100 prior to subtraction from the quantity established in steps 1, 2 and 3.
5. The value thus established will be multiplied by the quantity 256/5 to provide for display scaling.
6. The quantity thus established the steps 1 through 5 above will be divided by the stored value of S.

These steps will yield

$$\frac{\left(\frac{100 \cdot (V - RCC)}{10} + 3 \cdot 100 \cdot S - 100 \cdot \log Q\right) \cdot \frac{256}{5}}{100 \cdot S}$$

$$= \left(\frac{\frac{(V - RCC)}{10} - \log Q}{S} + 3\right) \cdot \frac{256}{5}$$

Had step five been omitted (multiply by 256/5), the result would have been the addition of the quantity 3 to the value of log W. This addition scales the range of log W, -3 to +2, to be 0 to +5. The multiplier of step 5 converts the log W + 3 to an integer between 0 and 256 in anticipation of output to the display.

For the calculation of W from log W, the scaling will be changed as required by the hyperbolic cordic function. Special scaling of the inputs to the cordic functions used to calculate logarithm and inverse-logarithm will be required as described in A. J. Jagodnik's memorandum, AJJ-29.

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APPENDIX D

Liquid Water Content Subroutine

LWC Subroutine

This subroutine solves the equation for liquid water content

$$W = \log^{-1} \frac{\frac{V - RCC}{10} - \log Q}{S} \qquad (1)$$

where V - RCC (= 10 log Z) is log Video corrected for the radar calibration constant RCC, Q is the phase-related coefficient and S is the phase-related exponent in

$$Z = QW^S . \qquad (2)$$

The subroutine makes use of two hyperbolic CORDIC algorithms described in AJJ-29 of Appendix E: HVEC to obtain log Q and HROT to evaluate the exponential in (1).

The inputs are left in the following registers prior to calling LWC:

R3: Average Video 2.56V (From LWTAB), $0 \leq V \leq 99$

R4: Exponent 100 S, $1.63 \leq S \leq 2.54$

R5: Coefficient Q, $100 \leq Q \leq 200000$

R9: Address in LWTAB

The subroutine expects to find the radar calibration constant at VRCC. The outputs remain in registers

R6: $(\text{Log } W + 3)2^{12}$; Log W scaled for LWCPLT (color display)

R7: 1000W ; W scaled for ANAPLT (line printer).

When LWC execution is complete, control is returned to the address in R8. Although other registers are used, their contents are stored and replaced; only the contents of R6 and R7 change as a result of calling LWC. In addition to the register outputs, average video is stored in the VIDAVG table, indexed by R9.

The input Q in R5 is tested and limited to the range mentioned above, then it is shifted left until its value is between 2^{23} and 2^{24}, with the number of shifts required (6 to 17) being contained in R1. The number in R5, $Q\,2^{R1}$, becomes the variable V in example 4, Figure 1 of AJJ-29 in Appendix E scaled so that V = 1 corresponds to 2^{24} in the computer. The quantities V + 1 and V - 1 are loaded into the X and Y input registers, then HVEC is executed. Although HVEC and HROT were written as subroutines, they are coded in-line within LWC because they are not used elsewhere. When HROT has ended,

2^{23} ln V remains in the Z register which is subsequently multiplied by 200 log e $\bullet$ 2^{28} so that the most significant part of the result ends up in the Y register as 100 log e $\bullet$ ln V $\bullet$ 2^{20}. Next, R1 is similarly multiplied so that R1 $\bullet$ 100 ln 2 $\bullet$ log e $\bullet$ 2^{20} resides in R0. Finally, R0 is subtracted from the constant Y'2D278D45' (100 log e $\bullet$ ln 2^{24} $\bullet$ 2^{20}) is added to Y so that its value becomes 100 log Q $\bullet$ 2^{20}.

The averaged video in R3, after correction for the similarly scaled calibration constant RCC, is limited to the range $-77 < R3 < 286$ and multiplied by a constant to become 10(V - RCC) 2^{20}. Next, Y which still contains 100 log Q $\bullet$ 2^{20} is subtracted from R3 and the result is divided by 100 $\bullet$ S in R4, leaving log W $\bullet$ 2^{20} in register Z which is then limited to the range $-3 \bullet 2^{20} < Z < 2 \bullet 2^{20}$. The Z register contents are then duplicated in output register R6 and a constant added to develop the final output (log W + 3) 2^{12} to be used in LWCPLT.

The number in Z is arithmetically altered by constants to change its base and rescale it so that (ln W - 6 ln 2) 2^{24} ends up in the Z register. The constant (ln 2 $\bullet$ 2^{24}) is added to Z and the number of additions counted in R1 until Z is greater than (1 - ln 2) 2^{24}. Now Z contains (ln W + (R1 - 6) ln 2) 2^{24}, Y is zeroed and the constant $2^{24}/(K - 1)$ is loaded into Y so that the exponential can be evaluated using HROT as in example 3, Figure 1 of AJJ-29 in Appendix E. After HROT, the addition of the sinh and cosh in X, and a shift left of six bits, that register contains W $\bullet$ 2^{R1} $\bullet$ 2^{24}. Additional shifting by R1 bits in the opposite direction yields W $\bullet$ 2^{24} in X which is rescaled to 1000 $\bullet$ W and left in R7 as the output for ANAPLT.

APPENDIX E

Hyperbolic CORDIC Subroutines

RAYTHEON

FORM 10-0557 (9-65) BOND

DIVISION	Equipment	Classification	Unclassified
Operation	EDL	Contract No.	DNA001-75-C-0050
Department	ADL	Distribution	As listed
To	J.H. Turner, Jr.	File No.	-
From	A.J. Jagodnik, Jr.	Memo No.	AJJ-29
Subject	Hyperbolic CORDIC Subroutines for Liquid Water Content (LWC) Determination System	Date	21 July 1975

References: Listed at end of memo

The CORDIC technique[1.-4] for computing transendental functions has been chosen for implementation of certain subroutines required in the LWC initialization and analysis phase software. Circular CORDIC subroutines CROT and CVEC, used in trigonometric operations in the LWC software, have been described.[5] This memo considers Hyperbolic CORDIC subroutines HROT and HVEC, needed in the LWC analyzer for evaluation of natural logs and antilogs. Hyperbolic CORDIC differs from the more-easily-visualized circular algorithms in that the vectors involved are constrained by a hyperbola rather than a circle. The hyperbolic CORDIC algorithms share the same advantages over alternative techniques as the circular algorithms: 1) They employ add, subtract, shift and compare operations available as rapidly-executable computer instructions, 2) The amount of memory required for stored constants is minimal, and 3) Two functions are obtained simultaneously.

Authors of CORDIC papers routinely point out how the circular algorithms can be converted to hyperbolic form simply by changing the stored constants and decision criteria. In actual practice, however, convergence problems require special attention not needed in the case of circular algorithms. The only treatment of these problems known to this author is to be found in Reference 4 which also suggests a solution that works. This comprehensive paper-which unifies algorithms elsewhere referred to as circular, linear, and hyperbolic CORDIC-also contains valuable information as to convergence domain and accuracy.

The CORDIC algorithms involve iterative operations among three registers X, Y, and Z in a process similar to that employed in successive approximation A/D converters. Details of the hyperbolic algorithms appear in Refernce 4 and will not be repeated here except to note that repetition of the fourth and thirteenth iterations was necessary to solve the previously mentioned convergence problem.

The schematic representations of Figure 1 show the functions which can be calculated by means of the two hyperbolic CORDIC subroutines, named HROT and HVEC. In the rotation mode (HROT), operations are performed such that the Z (hyperbolic angle) register is driven toward zero, while in the vectoring mode (HVEC) the Y register is driven toward zero. The constant K_i is a function only of the number of iterations but must take into account the two which are repeated. For 18 iterations, K_{-1} has been calculated as 0.828159361 on the 9820A. Note that this number is

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about half of the constant K_1 for circular CORDIC.

The first two examples which appear in Figure 1 involve straight-forward evaluation of hyperbolic functions; note the convergence domain limitations. It is interesting that X must be kept non-negative (observed experimentally). If the number in the X register is negative, then the hyperbola shifts to the other half plane (see Figure 1 of Reference 4) and the decision criteria cause rotations in exactly the wrong directions, so that the Z register always ends up at one or the other of its saturation limits. Example three illustrates the simplicity of exponential evaluation once HROT has been run. Finding logarithms, as in example 4, is a bit more tricky and makes use of an identity which requires addition and subtraction before HVEC is called. Note, however, that only a shift by one bit and no multiplication to correct for K_{-1} is needed since it cancels out in register Z. A side benefit of example 4 is that it also obtains $\sqrt{v}$ after a corrective multiplication.

HROT and HVEC (Figure 2) were intended to have the same 15-bit precision as that obtained in CROT and CVEC, but two more iterations were added (because of the convergence problem). Thus the hyperbolic routines employ 18 iterations, and at least 19 significant bits must be maintained in the three I/O registers. Inputs to X and Y can be scaled arbitrarily (what goes in comes out multiplied by K_{-1}), but numbers with fewer than 19 significant bits will result in increased algorithmic errors.

Inputs to the Z register must be scaled properly since the look-up table HALFAT has pre-determined scaling where a real-world value of unity corresponds to 2^{24} or Y'100 0000' in the Interdata 7/32 computer.

HROT and HVEC, coded separately to speed execution even though they differ only in the test on Z, were originally written as separate subroutines sharing the table HALFAT. When it was determined that each would be called only once during another subroutine (LWC), they were both included directly as part of that subroutine. Hence the missing addresses in Figure 2-the CAL assembly listing of HVEC, HROT, and HALFAT.

The fact that the Fourth and thirteenth iterations need to be repeated meant that the number of places to be shifted was not simply related to the index as in the circular algorithms. Rather than slow execution by testing I and branching, it was decided to include a shift number with each of the 18 entries in HALFAT which had sufficient room available. Thus, each full word in HALFAT (figure 2b) contains the shift number in its right most byte and the most significant 24 bits of the constant, $2^{32}\tanh^{-1}(2^{-\text{shift No.}})$ in the remaining bytes. During each iteration, the shift number is put into SAR by means of a load Byte instruction. After the shifts, SAR is again loaded from HALFAT but with the full word this time. SAR is then shifted right by eight bits to eliminate the shift humber and properly scale the constant. Even though the first entry in HALFAT is a negative number, the required positive quantity in SAR results because a logical shift right instruction was used.

Execution time for either hyperbolic CORDIC routine has been estimated as 663 microseconds. Test calculations of sinh, cosh, and Tanh^{-1} at various points scattered over the convergence domain revealed a peak error corresponding to 15-bit accuracy in the outputs.

References

1. "The Cordic Trigonometric Computing Technique," J.E. Volder, IRE Trans. on Electronic Computers Vol. EC-8, No. 3, pp. 330-334, September 1959.

2. "CORDIC Technique Reduces Trigonometric Function Look-up," Michael D. Perle, Zwicker Electric Co., N.Y., N.Y., Computer Design, June 1971.

3. "Hyperbolic CORDIC" J.S. Friedman, technical memo JSF:74:05, 29 August 1974.

4. "A Unified Algorithm for Elementary Functions," J.S. Walther, Hewlett-Packard Co., Spring Joint Computer Conference, 1971.

5. "Circular CORDIC Subroutines for Liquid Water Content (LWC) Determination System", A.J. Jagodnik Memo AJJ-19, 11 February 1975. Errata: The constant K_1 is 1.646760258 for 16 iterations. Page 5, Figure 2a, comment on line 35 should read: If I Lt 16 GTO AGAINC

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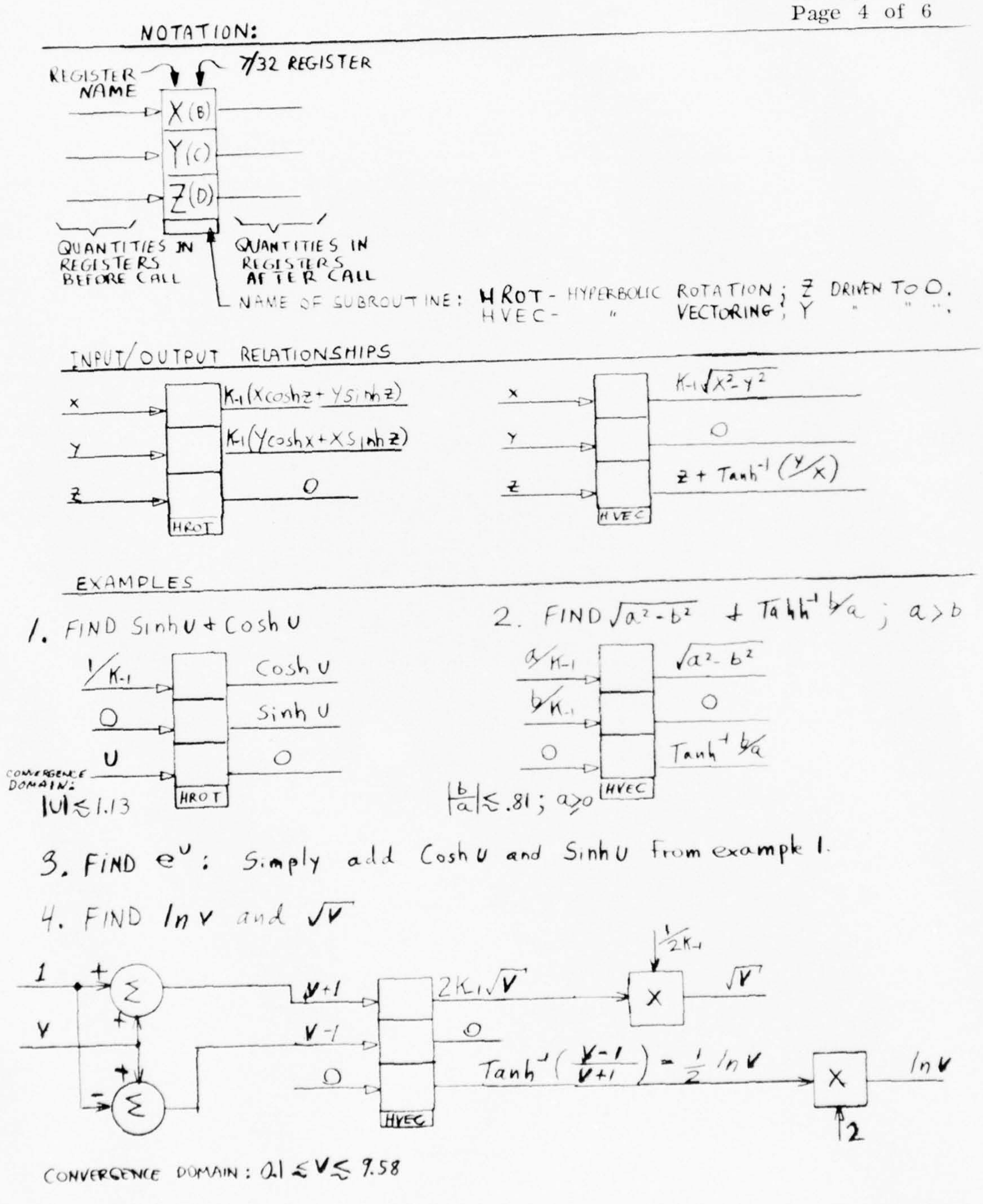

Figure 1. Hyperbolic CORDIC Input/Output Relationships and Examples of Applications

```
SAR      EQU   9       SHIFT NO./ALFA  REGISTER
I        EQU   10  (A) INDEX
X        EQU   11  (B) X  IO REGISTER
Y        EQU   12  (C) Y  "     "          EQUATES FOR
Z        EQU   13  (D) Z  "     "          BOTH HROT
XSH      EQU   14  (E) X  SHIFT "          AND HVEC
YSH      EQU   15  (F) Y   "    "

                         *    HVEC   (SHARES HALFAT TABLE WITH HROT)
004C8E  24A0                      LIS    I,0              I=INDEX;INCR BY 4 AT EACH STEP
004C90  08E5              LWCAAE  LR     XSH,X
004C92  08FC                      LR     YSH,Y
004C94  D39A 4000 4E13            LB     SAR,HALFAT+3(I)  SHIFT NO INTO SAR FROM TABLE
004C9A  EEE9 0000                 SRA    XSH,0(SAR)       SHIFT RIGHT SAR BITS
004C9E  EEF9 0000                 SRA    YSH,0(SAR)
004CA2  589A 4000 4E10            L      SAR,HALFAT(I)    GET ALFA FROM TABLE
004CA8  1098                      SRLS   SAR,8            GET RID OF SHIFT NO
004CAA  F9C0 0000 0000            CI     Y,0
004CB0  4310 4000 4CC2            BFC    1,LWCCCWV        IF Y>0; GTO CCW ROTATION
004CB6  0ABF                      AR     X,YSH            CW
004CB8  0ACE                      AR     Y,XSH            ROTATION
004CBA  0BD9                      SR     Z,SAR
004CBC  4300 4000 4CC6            B      LWCITV
004CC2  0B8F              LWCCCWV SR     X,YSH            CCW
004CC4  0BCE                      SR     Y,XSH            ROTATION
004CC6  0AD9                      AR     Z,SAR
004CC8  26A4              LWCITV  AIS    I,4
004CCA  F9A0 0000 0048            CI     I,72
004CD0  4210 FFBC                 BTC    1,LWCAAE         IF I<72; GTO LWCAAE
                         *    END OF HVEC
```

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Figure 2a. HVEC Assembly Listing (Part of LWC)

```
                                 863  *     HROT  (SHARES HALFAT TABLE WITH HVEC)
004DA2  24A0                     864              LIS    I,0
004DA4  08EB                     865  LWCAAL      LR     XSH,X
004DA6  08FC                     866              LR     YSH,Y
004DA8  E39A 4000 4E13           867              LB     SAR,HALFAT+3(I)
004DAE  EEE9 0000                868              SRA    XSH,0(SAR)
004DB2  EEF9 0000                869              SRA    YSH,0(SAR)
004DB6  589A 4000 4E10           870              L      SAR,HALFAT(I)
004DBC  1098                     871              SRLS   SAR,8
004DBE  F900 0000 0000           872              CI     Z,0
004DC4  4210 4000 4DD6           873              BTC    1,LWCCCWR          IF Z<0:  GTO CCW ROTATION
004DCA  0ACF                     874              AR     X,YSH
004DCC  0ACE                     875              AR     Y,XSH
004DCE  0B09                     876              SR     Z,SAR
004DD0  4300 4000 4DDC           877              B      LWCITR
004DD6  0BBF                     878  LWCCCWR     SR     X,YSH              CCW
004DD8  0BCE                     879              SR     Y,XSH
004DDA  0A09                     880              AR     Z,SAR
004DDC  26A4                     881  LWCITR      AIS    I,4
004DDE  F9A0 0000 0048           882              CI     I,72
004DE4  4210 FFBC                883              BTC    1,LWCAAL           IF I<72: GTO LWCAAL
                                 884  *    END OF HROT
004E10  8C9F 5401                896  HALFAT      DCY    8C9F5401,41628C02,20281203,10055904,10055904,800AB05
004E14  4162 8C02
004E18  2028 1203
004E1C  1005 5904
004E20  1005 5904
004E24  0800 AB05
004E28  0400 1506                897              DCY    4001506,2000307,1000008,800009,40000A,20000B
004E2C  0200 0307
004E30  0100 0008
004E34  0080 0009
004E38  0040 000A
004E3C  0020 000B
004E40  0010 000C                898              DCY    10000C,8000D,8000D,4000E,2000F,10010
004E44  0008 000D
004E48  0008 000D
004E4C  0004 000E
004E50  0002 000F
004E54  0001 0010
        Constant  Shift No.
```

Figure 2b. HROT and HALFAT Assembly Listings (Part of LWC)

APPENDIX F

Display Data Port Programming

RAYTHEON

FORM 10-0557 (9-65) BOND

DIVISION	Equipment	Classification	Unclassified
Operation	ADL	Contract No.	DNA001-75-C-0050
Department	ADL	Distribution	As Listed
To	J. H. Turner	File No.	-
From	A. J. Jagodnik, Jr.	Memo No.	AJJ-21
Subject	Display Data Port Programming	Date	26 March 1975

Reference: 1. AJJ-17, "Design Plan for the Display Data Interface of the Liquid Water Content Analyzer System," dated 17 Dec. 1974

2. Scan Converter and Contour Refresh Memory Equipment Information Report, June 1974.

The Display Data Interface design plan contains sections entitled "Operation of the LWCA Control Panel" and "Hardware/Software Interaction". The purpose of this memo is to expand upon the contents of these sections, based upon the existing hardware which differs slightly from that originally planned. The programmer should find here information needed to write assembly language programs for the purpose of communicating between the scan converter color displays and the analyzer (Interdata 7/32 minicomputer).

The first section consists of operating instructions for the LWCA control panel and scan conversion processor, while subsequent sections discuss addressing conventions and each of the three basic types of data transfers: Write Display Memory, Read Display Memory, and Cursor Data Entry. Programming examples are also included.

Operation of the LWCA Scan Converter

Scan converter operation is covered in Reference 2; the information presented here is intended to serve as a supplement and covers operation with the LWCA Control Panel illustrated in Figure 1. Except for the ERASE DISPLAY buttons, all of the switches on the control panel also serve as indicators controlled by their state and/or the DDI (Display Data Interface) within the scan converter. An exception is the control labeled DATA SOURCE TAPE which functions only as an indicator to denote the fact that the Precision Digital Video Integrator has been set to accept data from Mag Tape for display on the scan converter.

The LWCA TO DISPLAY controls, when lit, indicate that write and/or read data transfers are enabled in the hardware. They are affected by several controls on the Scan Conversion Processor as indicated in Table 1. The state of these controls can be uniquely determined from the status byte of the Display Data Port which has been assigned device number X'8B'.

Table 1

Scan Conv. Controls		LWCA to Display				Device X'8B' Status Byte
		Switches		Indicators		
Mode	Memory Control Store Video	Write On/Off	Read On/Off	Write On/Off	Read On/Off	0 1 2 3 4 5 6 7
A	All OFF	X	X	Lit	Lit	x x x 1 x 1 1 1
A	One or More ON	X	X	Dark	Lit	x x x 1 x 0 1 0
Not A	All OFF	Off	Off	Dark	Dark	x x x 0 x 0 0 1
		Off	On	Dark	Lit	x x x 0 x 0 1 1
		On	Off	Lit	Dark	x x x 0 x 1 0 1
		On	On	Lit	Lit	x x x 0 x 1 1 1
Not A	One or More ON	X	Off	Dark	Dark	x x x 0 x 0 0 0
			On	Dark	Lit	x x x 0 x 0 1 0

X = don't care

The scan converter will operate normally in the following mode switch positions: PPI, RHI, CAPPI and B. If the appropriate LWCA TO DISPLAY indicator is lit, the analyzer can read or write into the display memories. In mode switch position A, the necessary conditions for LWCA operation are set up; these are:

(1) Scan converter in RHI mode,

(2) LWCA TO DISPLAY READ indicator forced ON

(3) LWCA TO DISPLAY WRITE indicator forced ON if the converter memory buss is available (all STORE VIDEO switches OFF).

The scan converter ERASE VIDEO buttons used in normal operation do not erase the entire screen; the contour threshold legend area is left unchanged. In addition, a mask obscures from view certain areas within the ancillary data portion of the screen. These areas contain coded information available to the analyzer and needed by the contouring hardware. The ERASE DISPLAY buttons on the LWCA CONTROL PANEL not only erase the entire display, but also inhibit the mask so that the entire screen is available to display information from the processor. The mask and the legend are restored when the operator actuates the corresponding STORE THRESHOLDS button on the scan conversion processor.

The cursor can be made to appear in any display by depressing the appropriate CURSOR ON/OFF switch; the on state is indicated by illumination of the switch. The cursor, a blinking single point on the display, can be located anywhere on the screen by means of the CURSOR POSITION trackball.[1] The cursor changes color as a function of its surroundings so as to remain visible. During normal scan converter operation, the mask will obscure the cursor. If the cursor cannot be found, the following property may be useful: along the Top and Left edges of the display, the cursor will stop even if the trackball is rotated too far. At the bottom edge, the cursor disappears. When moved beyond the right edge, it reappears at the left where it finally stops about an inch from that edge; however, if the SEND DATA button were pressed with the cursor in such a position, the address would be wrong.

The color/intensity code covered by the cursor, as well as its coordinates, can be entered into the analyzer by pushing the appropriate SEND DATA button. The corresponding cursor must be switched-on for this action to be recognized. The SEND DATA switch will light when depressed, if the DDI control logic is in the proper state, and will extinguish about one-half second after the resulting interrupt has been serviced by the analyzer.[1] Pressing the INI button on the analyzer console should always turn off any SEND DATA indicators which are lit for whatever reason.

Display Conventions

The four display channels, numbered one through four, contain independent memories. Each memory is organized so that its address corresponds with the (X, Y) coordinates within a 248 by 320 point matrix as indicated in Figure 2. Each point can take on one of sixteen color/intensity combinations as listed in that figure. (The observed colors are a function of the settings of an array of switches in each memory interface unit; those colors listed correspond to the settings indicated in Figure 4-11 of Ref. 2.) Note that color 15 has a non-over write property: once this code occupies a point, the only way the color code at that point can be changed is by erasure.

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1. If any SEND DATA indicator is lit, no cursor will respond to the trackball.

The ancillary data area has significance only in normal scan converter operation; its outline is indicated in Figure 2, while the details of its contents appear in Figure 3. Information necessary for interpretation of the radar video data portion of the display (scaling, origin location, time, contour thresholds, and antenna angle) is obtainable by reading the four-bit codes in the patches indicated. Each of these patches contains the same four-bit code at all addresses within it. Most of the code patches have dimensions of 5 x 4 points (the same as the color patches) except for the origin location and scaling codes which are only 5 x 1. In either case, it is only necessary to read one point per patch, unless some sort of error correcting scheme is implemented to make use of the redundancy.

Points written as color 15 by a normally operating scan converter (not through the display data port) within the ancillary data area do not have the non-overwrite property. Any address in the ancillary data area which is not occupied by a 4 x 5 patch or an 8 x 5 character can be used for storage of a 4-bit word (e.g., to "mark" a stored video image) except for the 8 x 5 area under each color patch. Only the characters and color patches are displayed; everything else in the ancillary data area is masked. Again, the entire display area is erased (changed to color zero) and the mask is inhibited when an ERASE DISPLAY button is pushed, the entire area is now available to accept data from the analyzer.

General Comments on the Display Data Port

The hardware which comprises the display data port controller consists of two parts: an Interdata Universal Logic Interface (ULI) and a Raytheon-designed Display Data Interface (DDI). The ULI responds to device address X'8B' and contains interrupt and byte/halfword logic controlled by bits 0, 1 and 2 of the command byte (see Figure 4, note 2). Bit 2 should always be zero since the display data port operates only in the byte mode. Bits 0 and 1 affect interrupts in the following way: 01-interrupts enabled; 10-interrupts disabled but queued; 11-interrupts disarmed (neither accepted nor queued); 00-previous interrupt state unchanged. The ULI does not affect any bits in the status byte.

The DDI contains control logic which is described by the state diagram in Figure 4. Much of the notation here will not be of concern to the programmer. It is sufficient to note that state transitions are typically caused by execution of the 7/32 I/O instruction listed before the comment under each transition, or by a hardware-generated interrupt. Operation of the DDI control logic depends on the state of bits 4, 5 and 6 of the command byte as tabulated at the lower right of Figure 4. Also located there is a definition of the status byte, of which bits 3 through 7 are used.

Write Display Memory

Three distinct types of write operations which might be useful in various situations are supported in the DDI control logic. Controlled by bits 4, 5 and 6 of the command byte (Figure 4), they include:

(1) 0 0 0 - Write single point or multiple points the same color. The first write instruction transfers S_A, X_{AM} and color code, while succeeding pairs of instructions transfer (X_A, Y_A). The notation used here is explained in Figure 2; and the relationship to the Interdata bit numbers can be determined from Table 2.[2] This type of transfer might be useful where many points of the same color are to be plotted and it is not convenient to re-write S_A, X_{AM} and the color code for each point. An example is listed in Table 2. After the initial write instruction, the following pairs correspond to halfwords so that a halfword table containing (X_A, Y_A) values could be easily accessed sequentially using a write block instruction.

(2) 0 0 1 - Write single point or multiple points different colors. This sequence operates as the one described above, except that after the Y_A transfer, the next instruction transfers another number for S_A, X_{AM} and color.

(3) 0 1 0 - Write multiple points, fullword boundaries. This sequence operates as the one described above, except that after the Y_A transfer, the next instruction transfers nothing (see Figure 4, state W4), while the one following it transfers another number for S_A, X_{AM}, and color. This type of operation is intended for sequentially writing from fullword tables where each fullword contains S_A, X_{AM}, COLOR, X_A and Y_A for one point.

The Scan Converter, although it has an independent memory for each display, shares a memory address buss among the four display channels. When one or more STORE VIDEO switches is on, this buss is not available to the display data port and the write display memory operation is disabled in the hardware. It is also disabled for certain other switch settings as indicated in Table 1. Whenever the write operation is disabled, status bit 5 is zero. Before a write operation, it is good practice to check status to determine that bit 5 is one, although nothing will happen if a write is attempted, because the operation is disabled in the hardware. Status bit 4 should be checked to make sure it is zero; this bit indicates that a cursor data transfer is in progress and that the display data port is not available.

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2. See page 13 for table.

Read Display Memory

There are two types of read operations, depending on whether or not the scan converter memory buss is available. If the buss is available (all STORE VIDEO switches off; status bit 7 = 1), then a normal read, which operates in much the same way as the write display memory transfer described in the preceding section, can be executed. Otherwise, the process must be a slow read, which involves an interrupt service routine. Both types of read operations are inhibited if the read indicator is not lit (status bit 6 = 0, see Table 1).

Read Display Memory -- Normal

An example of this type of data transfer appears in Table 2. First, the status is sensed to ensure that the memory buss is available, the read indicator is on, and that no cursor data entry is in progress. Next, the proper command byte is output to device X'8B' and S_A, X_{AM}, X_A and Y_A are transferred just as for the write operation. At this point, a delay of at least six μsec; (for example, four BTCR 0, 0 (0200) instructions) must be executed so that the hardware is sure to have the required data ready. Lesser delays might work but have not been tried. Next, a read instruction is executed; the 4-bit color code appears in the four least significant bits of the second operand. Finally, a command byte can be output to leave the control logic in state I.

Read Display Memory -- Slow

If, in the preceding section, status bit 7 had been found to be zero, then a slow-read operation must be used. An example is found in Table 2. Steps 0 through 6 are the same as for a normal read, except that interrupts are enabled. The control logic, after step 6, ends up in state SR4 (see Figure 4) where it waits for an interrupt. This wait could last as long as 16 milliseconds and ends when the DDI has obtained data. Other processing can be executed during this wait interval. When the interrupt occurs, a simple interrupt service routine consisting of steps 8 through 10 of the example in Table 2 completes the operation.[3]

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[3] Details on interrupt processing can be found in Interdata Documents:

Model 7/32 Reference Manual, Pub. No. 29 - 399R02, Section 2.4
32-Bit Series " " Pub. No. 29 - 365R01, Chapter 7.

Cursor Data Entry

As does the slow-read operation, the cursor data entry makes use of an interrupt service routine and a data acquisition method which does not require the scan converter memory buss. There is, however, no long delay because, following the pressing of a SEND DATA button, no interrupt is generated until after all required data has been obtained. The cursor data entry requires that the DDI control logic be in state I and that the ULI has interrupts enabled; hence, step 0 of the example in Table 2. The remainder of this example is an interrupt service routine which checks the status to see that the interrupt was caused by a cursor data entry, outputs a command byte to disarm further interrupts, then transfers S_C, X_{CM}, X_C and Y_C to the second operand locations of the three read instructions. Finally, the control logic is returned to state I, interrupts are again enabled, and the original program status word is restored.

Programming Examples

The SCPLT subroutine listed in Table 3 was used in the Liquid Water Content display subroutine to take care of getting the ninth bit of X in the right place and to execute the necessary IO instructions for writing one point. The inputs were left in registers and the subroutine was called using BAL F, SCPLT. Because no other data transfer modes were being used in this application, the command byte was programmed to always leave the ULI with interrupts disarmed. SCPLT is called many times during the main program; it always leaves the control logic in state I. But in order to ensure that the very first point is plotted, the following instructions should be executed before SCPLT is called for the first time:

```
LHI     B, X'8B'
OC      B, DDICMD2
```

Thus forcing the control logic to state I.

Another way to structure SCPLT would put what is now line 72 (Table 3) after line 58, thus SCPLT would not leave the control logic in state I, but would force it there first each time it is called. A third method would involve forcing the control logic to state I only once, then not using any OC instructions at all in SCPLT itself. This method is the simplest and fastest, but depends on nothing disturbing the control logic between calls of SCPLT, where it would be left in state RW1 (Figure 4).

Table 4 lists a program to copy one display to another. It was written directly in machine language as a diagnostic to test the hardware, which it does very well since it accesses all display memory locations and exercises the read circuitry in the source display and the write circuitry in the output display. A good test of the hardware would consist of the following:

1) Store a test pattern or radar data image which contains all 16 colors in display 1; erase displays 2, 3 and 4.

2) Put Q = 0 0 0 0 and P = 0 0 2 0 into the program and run. Displays 1 and 2 should now be identical.

3) Put Q = 0 0 2 0 and P = 0 0 4 0 into the program and run. Displays 1, 2 and 3 should now be identical.

4) Put Q = 0 0 4 0 and P = 0 0 6 0 into the program and run. All displays should be identical.

5) Erase display 1.

6) Put Q = 0 0 6 0 and P - 0 0 0 0 into the program and run. All displays should again be identical.

Table 4 is shown set up for a normal read; to exercise the slow read, follow the directions at the end of the table. Execution of the copy program takes about three seconds in the normal read mode, and five seconds in the slow read mode. If the full 16 milliseconds delay were incurred at every point in the slow read mode, the program would require over 21 minutes for execution. The reason it only takes 5 seconds lies in the format adopted for scanning in the copy program. Examination of Table 4 will reveal that the copy process is basically accomplished by reading one point from the source display, writing that data into the same address in the output display, incrementing by one to the next Y address, then repeating. When Y reaches 248, X is incremented by one and Y goes back to zero. The fact that Y changes more rapdily then X is the key to the reason for the unexpectedly fast performance in the slow read mode. The average delay is only about 67 microseconds because of the way in which the copy-program scan interacts with the display raster-scan.

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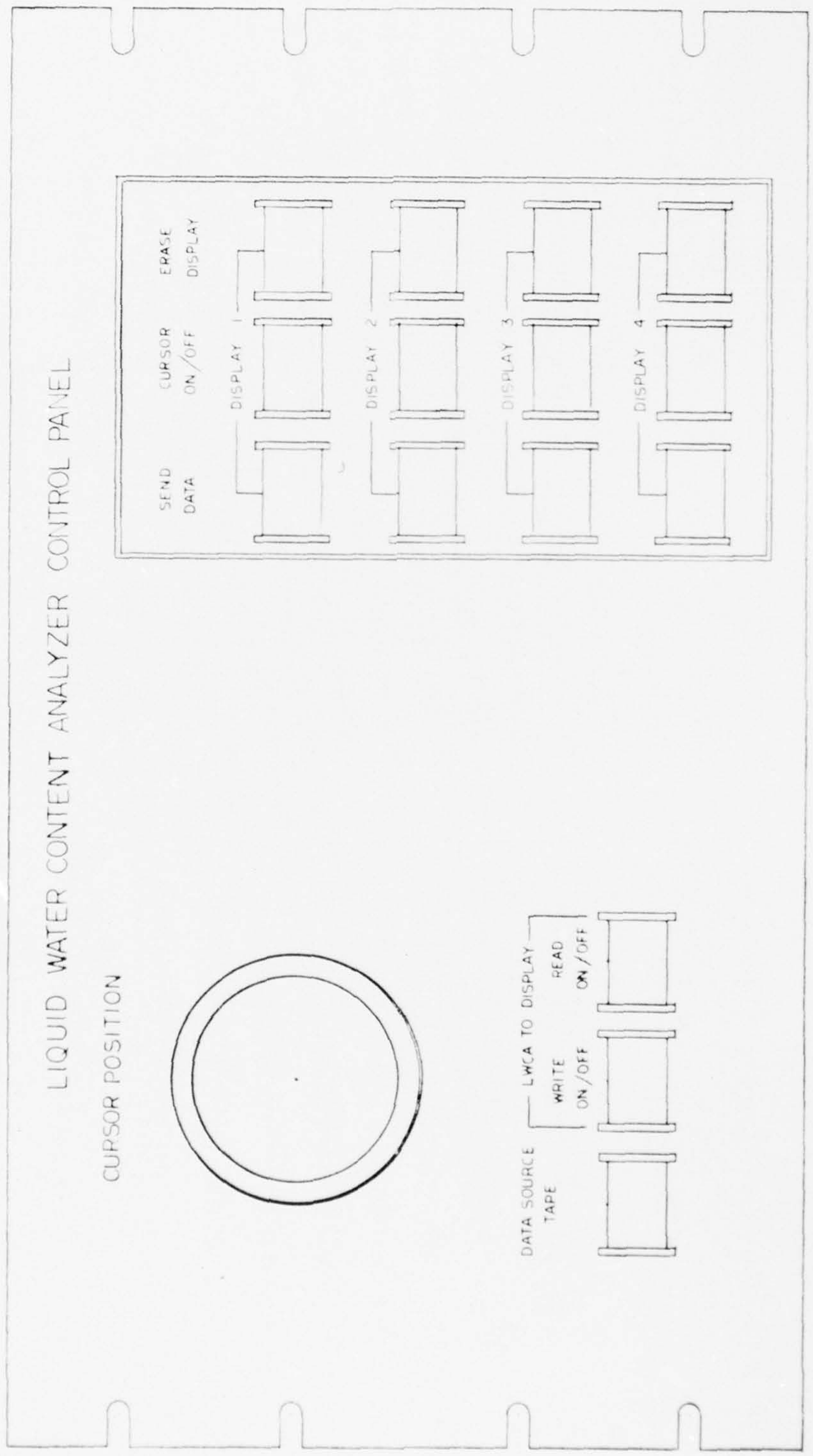
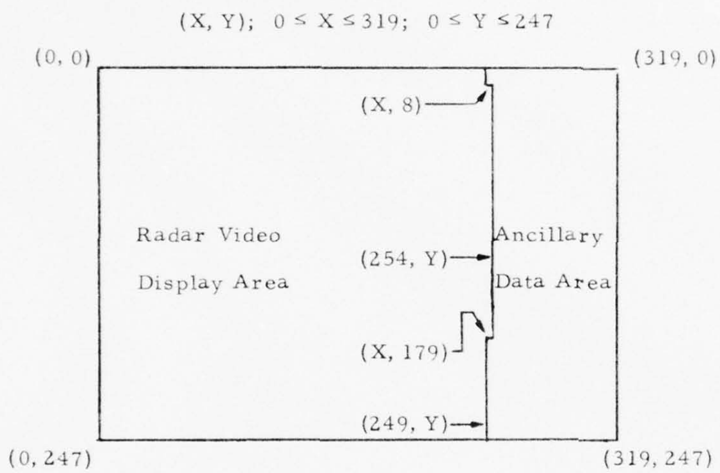


Figure 1. Control Panel



Represented by 8-bit codes:

Display coord. - X_A, Y_A

Cursor coord. - X_C, Y_C

Represented by 1-bit code:

Display coord. - X_{AM}

Cursor coord. - X_{CM}

(The most significant bit of X)

Represented by 2-bit codes:

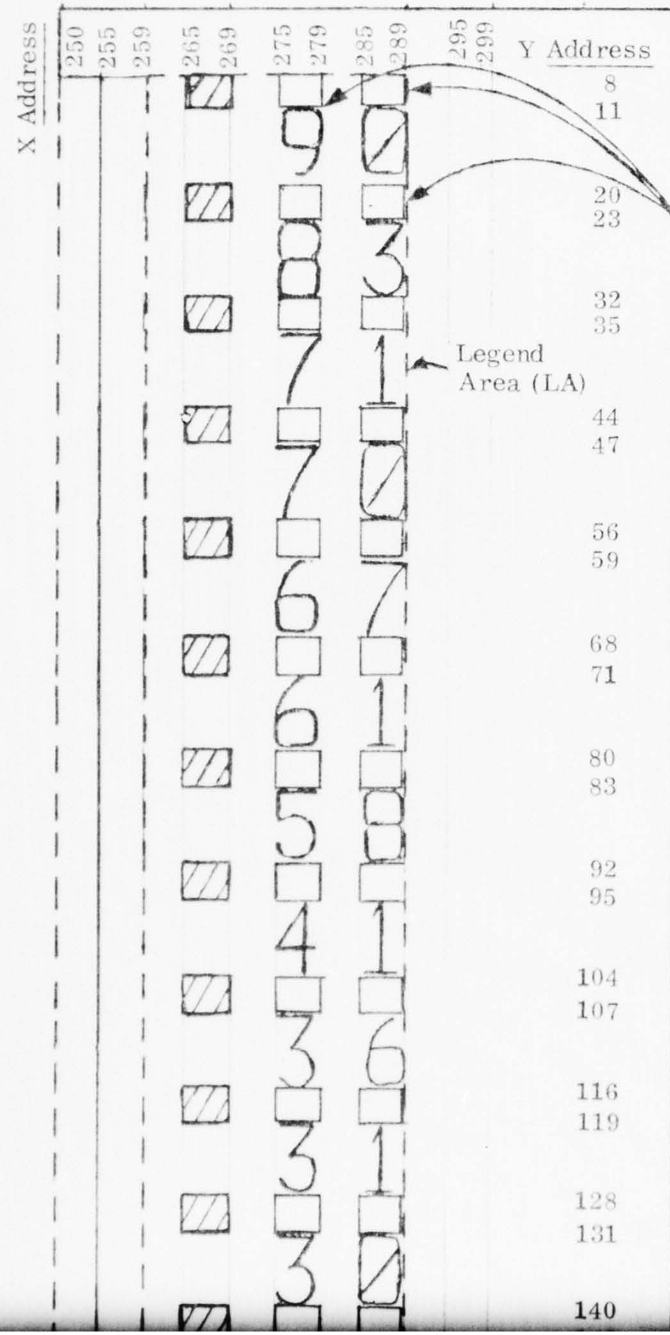
Display select - S_A

Cursor select - S_C

(Selects one of the four channels; 00 = display #1, 01 = display #2, etc.)

Color Code (4-Bits)	Relative Video Voltage			Observed Color
	Red	Green	Blue	
0	0	0	0	Black
1	7	0	7	Magenta
2	5	0	7	Violet
3	3	0	7	Blue-Violet
4	0	0	7	Blue
5	0	3	7	Cyan-Blue
6	0	7	7	Cyan
7	0	7	0	Green
8	3	6	3	Lt. Green
9	6	6	6	White
[illegible]	3	3	3	Gray
[illegible]	7	7	0	Yellow
[illegible]	6	2	3	Pink
[illegible]	7	2	0	Orange
[illegible]	7	1	0	Red-Orange
[illegible]	7	6	0	Red (Can't be overwritten)

Figure [illegible]. Display Addressing and Color Code Conventions for Each of the Four Channels



5 x 4 Patches, each containing a four-bit BCD code for the number below- - -
One patch above each number.
Each patch contains the same code in all 20 points.

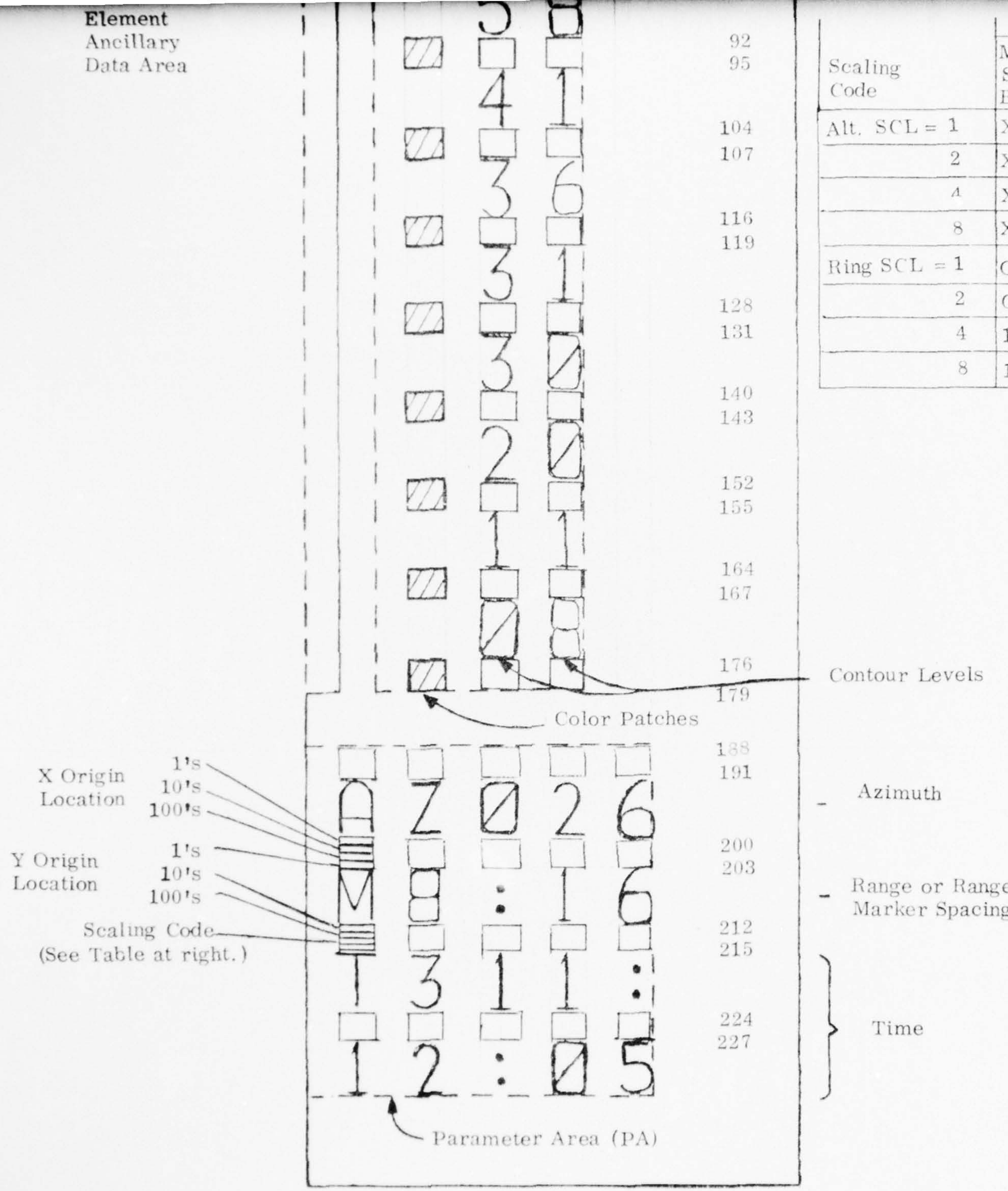
250 x 7D

Element
Ancillary
Data Area

Scaling Code	RD MSB			RD LSB
Alt. SCL = 1	X	X	O	O
2	X	X	O	1
4	X	X	1	O
8	X	X	1	1
Ring SCL = 1	O	O	X	X
2	O	1	X	X
4	1	O	X	X
8	1	1	X	X

Figure 3. Address Locations of Ancillary Data

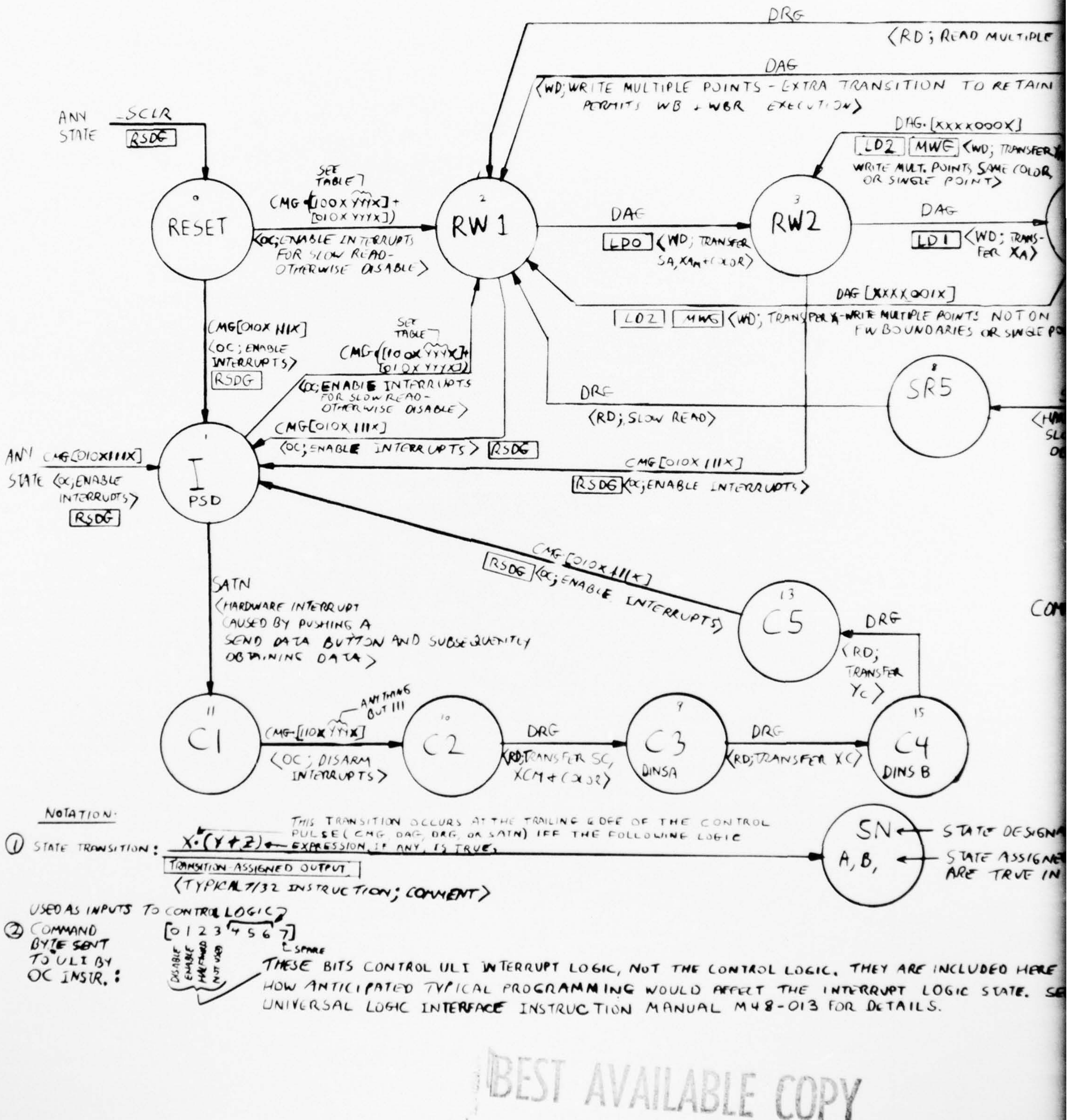
Element
Ancillary
Data Area



Scaling Code	RD MSB			LSB
Alt. SCL = 1	X	X	O	O
2	X	X	O	1
4	X	X	1	O
8	X	X	1	1
Ring SCL = 1	O	O	X	X
2	O	1	X	X
4	1	O	X	X
8	1	1	X	X

2

1



DRG
⟨RD; READ MULTIPLE
DAG
⟨WD; WRITE MULTIPLE POINTS - EXTRA TRANSITION TO RETAIN
PERMITS WB + WBR EXECUTION⟩
ANY STATE
_SCLR
RSDG
DAG·[XXXX000X]
LD2
MWE
⟨WD; TRANSFER
WRITE MULT. POINTS SAME COLOR, OR SINGLE POINT⟩
SEE TABLE
CMG·([100X YYYX] + [010X YYYX])
⟨OC; ENABLE INTERRUPTS FOR SLOW READ- OTHERWISE DISABLE⟩
0
RESET
2
RW1
DAG
LD0
⟨WD; TRANSFER SA, XAM + COLOR⟩
3
RW2
DAG
LD1
⟨WD; TRANSFER XA⟩
DAG [XXXX001X]
LD2
MWG
⟨WD; TRANSFER X-WRITE MULTIPLE POINTS NOT ON FW BOUNDARIES OR SINGLE PO
CMG[010X 111X]
⟨OC; ENABLE INTERRUPTS⟩
RSDG
SEE TABLE
CMG·([100X YYYX] + [010X YYYX])
⟨OC; ENABLE INTERRUPTS FOR SLOW READ- OTHERWISE DISABLE⟩
DRG
⟨RD; SLOW READ⟩
8
SR5
CMG[010X 111X]
⟨OC; ENABLE INTERRUPTS⟩
RSDG
ANY STATE
CMG[010X111X]
⟨OC; ENABLE INTERRUPTS⟩
RSDG
1
I
PSD
CMG[010X 111X]
RSDG
⟨OC; ENABLE INTERRUPTS⟩
CMG[010X 111X]
RSDG
⟨OC; ENABLE INTERRUPTS⟩
SATN
⟨HARDWARE INTERRUPT CAUSED BY PUSHING A SEND DATA BUTTON AND SUBSEQUENTLY OBTAINING DATA⟩
13
C5
DRG
⟨RD; TRANSFER YC⟩
COM
11
C1
ANYTHING BUT 111
CMG·[110X YYYX]
⟨OC; DISARM INTERRUPTS⟩
10
C2
DRG
⟨RD; TRANSFER SC, XCM + COLOR⟩
9
C3
DINSA
DRG
⟨RD; TRANSFER XC⟩
15
C4
DINS B
NOTATION:
① STATE TRANSITION:
X·(Y+Z)
THIS TRANSITION OCCURS AT THE TRAILING EDGE OF THE CONTROL PULSE (CMG, DAG, DRG, OR SATN) IFF THE FOLLOWING LOGIC EXPRESSION, IF ANY, IS TRUE.
TRANSITION ASSIGNED OUTPUT
⟨TYPICAL 7/32 INSTRUCTION; COMMENT⟩
SN
A, B,
STATE DESIGNA
STATE ASSIGNE ARE TRUE IN
USED AS INPUTS TO CONTROL LOGIC
② COMMAND BYTE SENT TO ULI BY OC INSTR.:
[0 1 2 3 4 5 6 7]
SPARE
DISABLE
ENABLE
HALT
NOT USED
THESE BITS CONTROL ULI INTERRUPT LOGIC, NOT THE CONTROL LOGIC. THEY ARE INCLUDED HERE
HOW ANTICIPATED TYPICAL PROGRAMMING WOULD AFFECT THE INTERRUPT LOGIC STATE. SE
UNIVERSAL LOGIC INTERFACE INSTRUCTION MANUAL M48-013 FOR DETAILS.

2

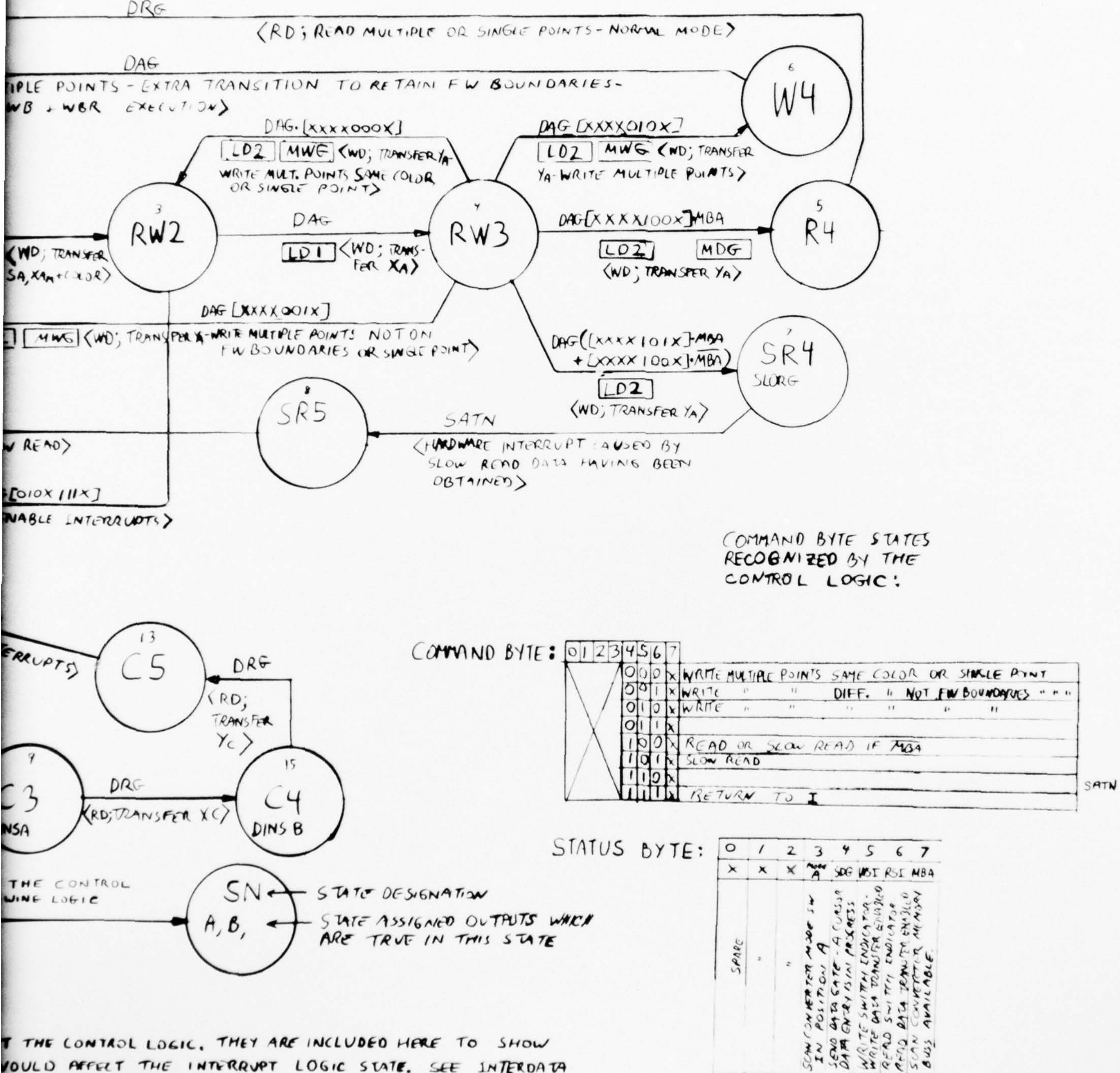


Figure 4. Control Logic State Diagram—DDI

Table 2. Examples of Display Data Port—I/O Operations
(For Interrupt-Driven I/O: ISP Table Loc. X' E16' = X' D0' + 2 x (Dev. No.: X' 8B')
Must Contain the Address of the Int. Serv. Routine

			ULI INPUTS		
			DIN (DATA) 0. . . . . . . 7 (MSB … LSB)	SIN (STATUS) 0. . . 4. 5. 6. 7 (MODE A, SDG, MSI, RSI, MBA)	0. (MSB)
OPERATION	TYPICAL STEPS	TYPICAL 7/32 INSTRUCTION			
WRITE DISPLAY MEMORY (TWO POINTS THE SAME COLOR)	0. SENSE STATUS	SS		x x x x 0 1 X X	
	1. CHECK STATUS FOR 01XX	NI, ETC			
	2. OUTPUT CMD BYTE OR INI	OC			
	3. OUTPUT CMD BYTE	OC			
	4. TRANSFER SA, XAM, AND COLOR DATA	WD			xS
	5. TRANSFER FIRST XA	WD			
	6. TRANSFER FIRST YA	WD			
	7. TRANSFER SECOND XA	WD			
	8. TRANSFER SECOND YA	WD			
	9. OUTPUT CMD BYTE, ENABLE INTERRUPT	OC			
READ DISPLAY MEMORY (NORMAL MODE ALLOWED IFF SIN7 IS TRUE OTHERWISE, THE SLOW READ MUST BE USED SEE NEXT PAGE)	0. SENSE STATUS			x x x x 0 x 1 1	
	1. CHECK STATUS FOR 0X11	NI, ETC			
	2. OUTPUT CMD BYTE, OR INI	OC			
	3. OUTPUT CMD BYTE	OC			
	4. TRANSFER SA, XAM	WD			xS
	5. TRANSFER XA	WD			
	6. TRANSFER YA	WD			
	7. DELAY - 6 µSec	4-BTCR			
	8. TRANSFER COLOR DATA	RD	x x x x —(COLOR— (RD)		
	9. OUTPUT CMD BYTE, ENABLE INTERRUPT	OC			
CURSOR DATA ENTRY (INTERRUPT SERVICE ROUTINE)	0 OUTPUT CMD BYTE				
	1. OBSERVE PULSE ON SATH LINE (HARDWARE INTERRUPT)			x x x x 1 x x x	
	2. CHECK STATUS, IN REG 3, SET ⓐ, FOR BIT 4 TRUE	NI, ETC			
	3. OUTPUT CMD BYTE, DISARM INTERRUPT	OC			
	4. TRANSFER SC, XCM, AND COLOR DATA	RD	x SCB SCA XCM ② —(COLOR— (RD)		
	5. TRANSFER XC	RD	— XC —		
	6. TRANSFER YC	RD	— YC —		
	7. OUTPUT CMD BYTE, ENABLE INTERRUPT	OC			
	8. RESTORE PROG. STATUS WORD	LPSWR			

① NOT AVAILABLE AT ULI OUTPUTS
② SEE NEXT PAGE

Port—I/O Operations
6' = X' D0' + 2 x (Dev. No.: X' 8B')
Int. Serv. Routine

	ULI INPUTS		ULI OUTPUTS				
	DIN (DATA) 0, ... 7 (MSB … LSB)	SIN (STATUS) 0, . . . 4, 5, 6, 7 (MODE A, SDG, WSI, RSI, MBA)	DOT (DATA) 0, ... 7 (MSB … LSB)	① COT (COMMAND) 0, 1, 2, 3 (DISABLE, ENABLE, HWM, MULTXD) 4, 5, 6, 7 (SPARE)	ULI CNTRL LINE ACTIVE	TYP. EXEC TIME -MS	CONTROL LOGIC STATE ENTERED
TYPICAL 2 INSTRUCTION							
SS		x x x x 0 1 X X			SRG	1+	-
NI, ETC						1+	-
OC				1 0 0 X 1 1 1 X	CMG	4	RESET OR I
OC				1 0 0 X 0 0 0 X	CMG	4.	RW1
WD			② x S_{AB} S_{AA} X_{AM} —COLOR (WD)—		DAG	3.75	RW2
WD			— X_A —		DAG	3.75	RW3
WD			— Y_A —		DAG	3.75	RW2
WD			— X_A —		DAG	3.75	RW3
WD			— Y_A —		DAG	3.75	RW2
PT OC				0 1 0 X 1 1 1 X	CMG	4	I
		x x x x 0 x 1 1			SRG	1+	
NI, ETC							
OC				1 0 0 X 1 1 1 X	CMG	4.	RESET OR I
OC				1 0 0 X 1 0 0 X	CMG	4.	RW1
WD			② S_{AB} S_{AA} X_{AM} x x x x		DAG	3.75	RW2
WD			— X_A —		DAG	3.75	RW3
WD			— Y_A —		DAG	3.75	R4
4-BTCR					-	6+	
RD	x x x x —COLOR (RD)—				DRG	3.75	RW1
T OC				0 1 0 X 1 1 1 X	CMG	4.	I
				0 1 0 X 1 1 1 X	CMG	4	I
(HARDWARE INTERRUPT)		x x x x 1 x x x					C1
F NI, ETC							
OC				1 1 0 X 1 1 0 X	CMG	4.	C2
RD	② x S_{CB} S_{CA} X_{CM} —COLOR (RD)—				DR	3.75	C3
RD	— X_C —				DR	3.75	C4
RD	— Y_C —				DR	3.75	C5
OC				0 1 0 X 1 1 1 X	CMG	4.	I
LPSWR							

① NOT AVAILABLE AT ULI OUTPUTS
② SEE NEXT PAGE

Table 2. (Continued)

OPERATION	TYPICAL STEPS	TYPICAL 7/32 INSTRUCTIONS	ULI INPUTS DIN(DATA) 0 . . 1 . . 7 MSB … LSB	ULI INPUTS SIN(STATUS) 0 . . . 4 . 5 . 6 . 7 MODE A SDG NSI RSI MBA	0 MSB
READ DISPLAY MEMORY (SLOW)	0. SENSE STATUS	SS		x x x x 0 x 1 0	
	1. CHECK STATUS FOR 0X10				
	2. OUTPUT CMD BYTE OR INI	OC			
	3. OUTPUT CMD BYTE, ENABLE INTERRUPT	OC			
	4. TRANSFER SA, XAH	WD			
	5. " XA	WD			
	6. " YA	WD			
	7. INTERRUPT WHEN DATA IS READY (DELAY WILL VARY BETWEEN 0 AND 16 MILLISECONDS)	—			
INTERRUPT SERVICE ROUTINE	8. TRANSFER COLOR DATA RD	RD	x x x x — RD —		
	9. OUTPUT CMD BYTE	OC			
	10. RESTORE PROG STATUS WORD	LPSWR			

② DISPLAY + CURSOR SELECT CODES

S_{AB} / S_{CB}	S_{AA} / S_{CA}	DISPLAY #
0	0	1
0	1	2
1	0	3
1	1	4

2

Table 2. (Continued)

	ULI INPUTS		ULI OUTPUTS					
	DIN(DATA)	SIN(STATUS)	DOT(DATA)	COT(COMMAND)		ULI CNTRL LINE ACTIV	TYP EXEC TIME MS	CONTROL LOGIC STATE ENTERED
	0 . . . 1 . . . 7	0 . . . 1 4 . 5 . 6 . 7	0 . . . 1 . . . 7	0 . 1 . 2 . 3	4 . 5 . 6 . 7			
L FUNCTION MIX	MSB … LSB	MODE A, SOG, WSI, RSI, MBA	MSB … LSB	DISABLE, ENABLE, MWM, WWUXD	RW, SQB, SQA, SPARE			
		x x x x 0 x 1 0				SRG	17	
C				1 0 0 x	1 1 1 x	CMG	4	RESET OR I
C				0 1 0 x	1 0 x x	CMG	4	RW1
VD			② · SAO SAW XAM x x x x			DNG	3.75	RW2
VD			— XA —			DAG	3.75	RW3
VD			— YA —			DAG	3.75	SR4
—						SATN		SR5
RD	x x x x —RD—					DAG	3.75	RW1
OX				0 1 0 x	1 1 1 x	CMG	4	I
PSWR								

Table 3. SCPLT Subroutine

```
                                        INPUTS: Reg. X, x-coord. 0≤X≤ 319
                                                Reg. Y, y-coord. 0≤Y≤ 247
                                                Reg. C, S_A in bits  25&26, color in bits 28-31,
                                                               all other bits zero.
                                                Reg. F, return address.

000082I  C8B0 008B              SCPLT     LHI    B,X'8B'     Device code in reg. B.
000086I  DEB0 4000 00BEI                  OC     B,DDICMD1   Output Cmd-disarm int, DDI to st. RW1.
00008CI  C9D0 0100                        CHI    X,X'100'    Compare X to 256.
000090I  4210 4000 00B0I                  BM     SCPLTA      If X<256, go to SCPLTA.
000096I  CBD0 0100                        SHI    X,X'100'    Decrease X by 256.
00009AI  CAC0 0010                        AHI    C,X'10'     Make bit 27 of C a 1.
00009EI  9ABC                             WDR    B,C         Write cont of reg C (S_A,X_AM,Color).
0000A0I  9ABD                             WDR    B,X          "    "   "  "  X (input X-256).
0000A2I  CAD0 0100                        AHI    X,X'100'    Restore X to what it was.
0000A6I  CBC0 0010                        SHI    C,X'10'      "     C "    "   "  "
0000AAI  4300 4000 00B4I                  B      SCPLTB      Go to SCPLTB.
0000B0I  9ABC                   SCPLTA    WDR    B,C         Write cont of reg C
0000B2I  9ABD                             WDR    B,X          "    "   "  "  X
0000B4I  9ABE                   SCPLTB    WDR    B,Y          "    "   "  "  Y
0000B6I  DEB0 4000 00C0I                  OC     B,DDICMD2   Output Cmd-disarm int,DDI to st. I.
0000BCI  030F                             BR     F           Return to the address in reg. F.
0000BEI                                   ALIGN  2
0000BEI  C200                   DDICMD1   DC     X'C200'
0000C0I  CE00                   DDICMD2   DC     X'CE00'
```

Table 4. Program to Copy One Display to Another

6000	C8A0	LHI	A,Q	source display: 1 2 3 4
2				Q ; 0000 0020 0040 0060
4	C8B0	LHI	B,P	output display: 1 2 3 4
6				P : 0000 0020 0040 0060
8	C880	LHI	8,8B	device code in reg. 8.
A	008B			
C	C890	LHI	9,C8	cmd byte for read in reg. 9.
E	00C8			
6010	C850	LHI	5,C2	cmd byte for write in reg. 5.
2	00C2			
4	24D0	LIS	D,0	zero reg. D.
6	24E0	LIS	E,0	"" " E.
8	9E89	OCR	8,9	output cmd byte for read.
A	9A8A	WDR	8,A	write S_A,X_{AM}
C	9A8D	WDR	8,D	" X_A
E	9A8E	WDR	8,E	" Y_A
6020	0200	BTCR	0,0	delay (No-op)
2	0200	BTCR	0,0	"
4	0200	BTCR	0,0	"
6	0200	BTCR	0,0	"
8	9B8C	RDR	8,C	read data into reg. C.
A	C4C0	NHI	C,F	mask all but the 4 lsb of reg. C.
C	000F			
E	9E85	OCR	8,5	output cmd byte for write.
6030	0ACB	AR	C,B	get the output display code in reg. C.
2	9A8C	WDR	8,C	write S_A,X_{AM},Color
4	9A8D	WDR	8,D	" X_A
6	9A8E	WDR	8,E	" Y_A
8	26E1	AIS	E,1	increment Y_A by 1.
A	C9E0	CHI	E,F8	compare Y_A with 248
C	00F8			
E	4320	BNP	6018	if $Y_A \leq 248$, go to 6018.
6040	4000			
2	6018			
4	26D1	AIS	D,1	increment X_A by 1.
6	24E0	LIS	E,0	zero Y_A.
8	C9D0	CHI	D,100	compare X_A with 256.
A	0100			
C	4210	BM	6018	if $X_A < 256$, go to 6018.
E	4000			
6050	6018			
2	4330	BNE	6064	if $X_A \neq 256$, go to 6064.
4	4000			
6	6064			
8	C9D0	CHI	D,13F	compare X_A with 319.
A	013F			
C	4320	BNP	6018	if $X_A \leq 319$, go to 6018.
E	4000			
6060	6018			

Table 4. (Continued)

```
6062   2200     BFBS   0,0      branch unc. to self.
   4   CAA0     AHI    A,10     add 16 to reg. A (make X_AM=1).
   6   0010
   8   CAB0     AHI    B,10      "  "  "  "  B  "  "
   A   0010
   C   4300     B      6018      go to 6018.
   E   4000
6070   6018
```

To do the same task using the slow read mode, change:

```
600E   004A                     cmd byte for slow read, interrupts enabled.

6020   2200     BFBS   0,0      branch unc. to self.
```

and include the following interrupt service routine:

```
6100   2612     AIS    1,2      increment reg. 1, the loc part of the PSW,
                                by one halfword to bypass the 2200 at 6020.
6102   1800     LPSWR  0,0      restore the PSW
```

Run with immediate interrupts enabled, in reg. set 0. (PSW=4000)
In the interrupt service pointer table, at D0+2x8B, put the starting address of the interrupt service routine:

```
0E16    6100
```

Note: This program was written diectly in machine language; it was never assembled by CAL. The assembler notation included here is incorrect for CAL in that all numbers listed are in hex. In CAL, such numbers must be represented as X'NNNN' or Y'NNNNNNNN', except for 0-9.

APPENDIX G

Radar I/O Drivers

The LWCA minicomputer to radar interface consists of two software groups, the video interface and the ancillary data interface. These are operative both for data input (recording) and output (playback).

The interface programs have been implemented as general purpose "I/O drivers" to allow other LWC system modifications without any changes to these modules. There are 4 entry points to the subroutines, one each for video input, video output, ancillary input and ancillary output. The calling sequence for any of the 4 is as follows:

```
BAL    RX, SUBRTNE        GOTO DESIRED SUBROUTINE
DC       Z(ERREXIT)       TRANSFER ADDRESS IF ERROR
                          OCCURED
```

The desired entry point name is used in place of SUBRTNE, and the desired return address register is used for RX. If no error occurs in the execution of the subroutine, control is returned to the location following the "DC" statement when the subroutine operation is complete. If an error is detected control is transferred to the location whose label is substituted for ERREXIT, and execution continues from that point. When an error occurs, register 10 contains an error flag, to be defined below.

The individual entry points are set up as follows:

Video Input

Entry name: VIDINP
Number of bytes to transfer: in location RNUMBIN
Location for start of transfer: VBUF + 32
Note: Actual transfer starts at VBUF + 20, to allow for synchronization with interface hardware. Actual useful data starts at VBUF + 32 when transfer is complete.
Error List:

0 No error
1 No selector channel start - 6 second timeout
2 No selector channel stop - 2 millisecond timout

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LIQUID WATER CONTENT ANALYZER. INSTRUCTION MANUAL.(U)
SEP 75 J H TURNER, A J JAGODNIK, W C ANDERSON DNA001-75-C-0050
UNCLASSIFIED ER75-4389 DNA-4129F NL

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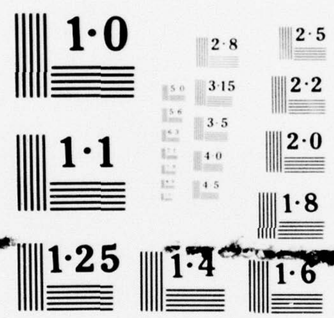

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3 Selector channel status non-zero when transfer complete - probable memory error

4 Full transfer not completed - abnormal end

5 Selector channel being busy to start - 6 second timeout

Subroutines used:

VIDINP	Transfers control to VIDIST
VIDIST	Sets up read command and transfers control to VID1
VID1	General purpose video I/O routine
IULI	Universal logic interface interrupt routine ("dump" pulse interrupt)
ISELCH	Selector channel end of operation interrupt routine (end of transfer interrupt)

Special requirements: The actual Input or Output transfer from or to the radar hardware is held up until the "dump" pulse is received, then proceeds at near memory speed. If no dump signal is received for approximately 6 seconds after the request for transfer, an error exit is made.

Video Output

Entry name: VIDOUT

Number of bytes to transfer: see VIDINP

Location for start of transfer: see VIDINP

Error List: see VIDINP

Subroutines used:

VIDOUT:	Transfer control to VIDOST
VIDOST:	Sets up write command and transfers control to VID1
VID1 to ISELCH:	Same as VIDINP

Special requirements: same as VIDINP

Ancillary Data Input

Entry name: ANCINP

Number of bytes to transfer: 8

Location of start of transfer: VBUF

Error List:

0 No error

1 No data available interrupt since last read/write

2 Inputs (or outputs) all zero

ANCINP: Transfer control to ANCIST

ANCIST: General Purpose ancillary data I/O setup subroutine

DELTAS: Determine direction of theta and phi motion (positive or negative)

DELTAFIX: Smooth average theta and phi differences, pass to pass

IULI2I: ULI interrupt processor for reading ancillary data via the multiplexor channel in response to the dump pulse.

Special requirements: Exits on error if no dump pulse is received between calls (no new data available) or if the data is all zeros, an illegal condition. The theta and phi directions on each pass are differenced from the previous pass and averaged to provide an indication of "positive" or "negative" position change, with some hysteresis to allow for indicator wobble. These flags are used to set direction bits in Θ and $\emptyset$ in VBUF to guarantee the proper "painting" of display fields when consecutive data samples are not contiguous on the display.

Data is not actually transferred when the routine is called, but rather by the interrupt routine (IULI2I or IULI2O) when the dump pulse occurs.

Ancillary Data Output

Entry name: ANCOUT

Number of bytes to transfer: 8

Location of start of transfer: VBUF

Error List: Same as ANCINP

Subroutines:

ANCOUT: Transfer control to ANCOST

ANCOST: Initializes theta and phi direction flags and transfers control to lable ANC3 of ANCIST

ANCIST: General purpose ancillary data I/O setup subroutines,

DELTAS and

DELTAFIX: see ANCINP

IULI2O: ULI interrupt processor for writing ancillary data into the multiplexor channel in response to the dump pulse

Special Requirements: Same as ANCOUT

All of the above subroutines are described in detail in a general purpose program design language (PDL) in Appendix H.

The following references should be made to aid in a complete understanding of data formats, equipment operation, etc.

Raytheon Memo JHT:75:27 Revised, Liquid Water Content (LWC) Constants, Variables and Tables/contains VBUF format.

Interdata Manual 29-399 7/32 User's Manual/Contains extended selector channel interface description.

Interdata Manual 29-311 Universal Logic Interface Instruction Manual/ ULI interface description.

APPENDIX H

LWC Radar Input/Output Drivers
Outlined in Program Design Language

*VIDIST - VIDEO INPUT SUBROUTINE

VIDIST   Save registers to be used in subroutine

Get read Command

<u>Go to</u> VID1

<u>End</u> Subroutine VIDIST

VID1   Save Command

Save Last Byte address for transfer

Save ULI Interrupt routine address into trap

Set up registers for status check

(VID9)[1]   <u>Do while</u> selector channel busy

    <u>If</u> 6 second timer has expired

        <u>then</u> flag selector channel hung (5)

            <u>Go to</u> VIDERR

        <u>Else</u> decrement TIMBR

(VID8)   Save selector channel interrupt routine address in trap

Output a selector channel stop

Flag no interrupts received

Enable synch interrupt

(VID3)   <u>Do until</u> synch interrupt received

    <u>If</u> 6 second timer has expired

        <u>then</u> flag no synch interrupt (1)

            <u>Go to</u> VIDERR

        <u>Else</u> decrement timer

(VID2)   <u>Do until</u> selector channel transfer is complete

    <u>If</u> 2 millisecond timer has expired

        <u>then</u> flag no selector channel stop (2)

            <u>Go to</u> VIDERR

        <u>Else</u> decrement timer

(VID4)   <u>If</u> selector channel status is not "successful transfer"

    <u>Then</u> flag error in transfer (3)

        <u>Go to</u> VIDERR

(VID7)   <u>If</u> last byte address not desired L. B. A.

    <u>Then</u> flag error - Abnormal end (4)

1. Labels which are not required in PDL are enclosed in parenthesis

```
VIDERR    Clear Selector Channel
          Restore the original register values
          If transfer had no errors
                Then return (to call point)
                Else return (to error exit point)
          End subroutine VIDOST

*IULI     Universal Logic Interface (ULI) interrupt Processor

IULI      Turn off ULI interrupt
          Start Selector channel I/O
          Flag synch interrupt received
          Return
          End subroutine IULI

*ISELCH   Selector Channel Interrupt Processor
ISELCH    Save selector channel status as done flag return
          End subroutine ISELCH

*ANCIST   Ancillary Data Input

ANCIST    Save registers to be used in this subroutine
          Call Deltas (update direction flags in Θ and Ø)
          Get ULI 2 input interrupt processing routine address

ANC3      Save in ULI 2 interrupt trap
          Turn on ULI 2 Interrupt
          If first pass through routine
                Then Clear ancillary data buffer area

(ANC4)          Else if interrupt has not been received
                     Then flag no interrupt received (1)
                          Go to ANCERR
(ANC2)               If data is all zero
                          Then flag bad data (2)

ANCERR    Clear interrupt received flag
          Restore Registers to original values
          If no errors occurred
                Then return (to call point)
                Else return (to error exit point)
          End subroutine ANCIST
```

```
*ANCOST   Ancillary Data Output Routine
ANCOST    Save registers to be used in this routine
          If not first pass
                Then Call  DELTAS (to update Θ and Ø Positions)
                   If Theta direction is positive
                         Then flag "positive" in ANCMSK+2
                         Else flag "negative" in ANCMSK+2
                   Get address of output ULI interrupt routine
                   Go to ANC3 (in routine ANCIST)
                Else set Θ and Ø  directions to unknown
                   Save current Θ  and Ø as "last" values
                   Go to ANC6
          End subroutine ANCOST

*Deltas - Subroutine to find the new Θ  and Ø positions

DELTAS    Re = current Θ - last Θ  (THETAL)
          Call DELTAFIX ( to compute average difference)
          DTHEA = Average difference in Θ
          If Θ direction = negative
                Then THEDIR =  - 1
                Else THEDIR = 1
          Re =  Current Ø  - Last Ø (PHIL)
          Call DELTAFIX   (to compute Ø average)
          DPHIA = Average Difference In Ø
          If Ø direction = negative
                Then PHIDIR =  -1
                Else PHUDIR = 1
          THETAL = Current Θ;  PHIL = Current Ø
          Return
          End subroutine  DELTAS
*DELTAFIX - Subroutine to average differences

DELTAFIX RB = Sign flag for average (Θ or Ø )
          If sign = minus
                Then compliment average
          RF = average/4
          If RF Not = 0
                Then if sign was negative
                         Then compliment RF
```

DFIX 2	RE = RE - RF (subtract average from current value)
	<u>Return</u>
	<u>End</u> Subroutine DELTAFIX
*IULI2I	ULI Input interrupt routine
IULI2I	VBUF = Data from Ancillary Data Port
	<u>If</u> servo angle 90° (VBUF + 6)
	<u>Then</u> set angle = 0°
IUL1	ULINF = '8000' (flag interrupt occurred)
	<u>Return</u>
	<u>End</u> subroutine IULI2I
*IULI 2O	ULI 2 output interrupt routine
IULI2O	Set Ø Direction bit from ANCMSK
	Output data from VBUF
	Clear extra Bit in Ø
	<u>Go to</u> IUL1
	<u>End</u> Subroutine IULI2O

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